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References:

- Raman, C. V. (1949) The theory of the Christiansen experiment. *Proc. Indian Acad. Sci., A*, 29: 381-90.
Sahni, B. (1936a) Wegener's theory of continental drift in the light of Palaeobotanical evidence. *J. Indian bot. Soc.*, 15: 31-32.
Sahni, B. (1936b) The Karewas of Kashmir. *Curr. Sci.*, 5: 10-16.

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Professor M. A. Govinda Rau, M.A., Ph.D., F.A.Sc., M.I.I. Chem. E.

1901-1954

Obituary

M. A. Govinda Rau

Professor M. A. Govinda Rau, Director, A. C. College of Technology, University of Madras, died on the 19th November 1954 and by his death the profession of chemical engineering in India has lost a pioneer and leader; the A. C. College and the University of Madras have lost an extremely able and conscientious teacher and administrator.

Govinda Rau was born on the 26th August 1901 in Viswamalsamudram, Trichinopoly District, Madras State. His father was Rao Bahadur M. C. S. Ananthapadmanabha Rau of the Indian Educational Service, who was for many years Professor of Physics in the Presidency College, Madras, and for some time Principal of the Government College, Kumbakonam. He went to school first in his village and later at Saidapet, Madras, winning the first prize in all the classes. He was a student in the Presidency College, Madras, from 1917 to 1922, passing the Intermediate examination in the first class and first in the University in physics and mathematics, and passing the B.A. (Honours) examination in chemistry with a high second class and second in rank. As part of the course in the Honours School of Chemistry, he had Electrochemistry as a special subject. He was awarded the Jagirdar of Arni Gold Medal in Chemistry in 1922 and the Sir William Wedderburn Prize for research in Chemistry in 1924. From 1922 to 1925 he carried out research in physical chemistry under Professor H. E. Watson in the Indian Institute of Science, Bangalore, and he worked with Professor F. G. Donnan in the University College, London, from 1925 to 1928. On the basis of a thesis entitled "Influence of frequency on the dielectric constants of substances," he was awarded the Ph.D. of London University in 1928. He was on the staff of the Indian Institute of Science, Bangalore, from 1928 to 1944, first as Research Assistant to Professor H. E. Watson, and later as Research Assistant to Sir C. V. Raman. In 1940 he organized the Department of Chemical Engineering in the Indian Institute of Science and he held charge of the Department for four years. In 1944 he joined the A. C. College of Technology, University of Madras, as Reader in Chemical Engineering, and shortly after-

wards he was appointed Professor of Chemical Engineering and Director of the College.

Rau's work on the determination and interpretation of dipole moments and his theory of the solvent effect in dipole moment measurements are major contributions to physics and physical chemistry.

From a study of light scattering in liquids Raman and Krishnan (*Proc. Roy. Soc.*, 1928, 117A, 589) in 1928 derived an equation for the effect of anisotropy on the induced and orientation polarisations of pure liquids. Subbaramaiya (*Proc. Indian Acad. Sci.*, 1934, 1A, 355) extended the equation to liquid mixtures, and Rau (*Proc. Indian Acad. Sci.*, 1935, 1A, 489, 498) modified it further to cover the case of an infinitely dilute solution of a polar solute in a non-polar solvent. By representing the solute as an ellipsoidal cavity of the same shape as benzene, Rau was able to apply his equation to measurements on nitrobenzene in various solvents, obtaining a value for the molar polarization in agreement with the observed value in the vapour state.

Lunt and Rau (*Proc. Roy. Soc.*, 1930, 126A, 213) determined the dielectric constant of benzene, ether, chloroform, ethanol, acetone, nitrobenzene and aniline and the conductivity of the last four substances in the frequency range 1 to 10^3 kc. No variation of the constant was observed for benzene, ether and chloroform; for the other liquids there was a slight increase in the range 10^2 to 10^3 kc. In this range the conductivity of aniline diminished rapidly as the frequency increased, that of nitrobenzene diminished slightly, and the conductivities of ethanol and acetone did not vary.

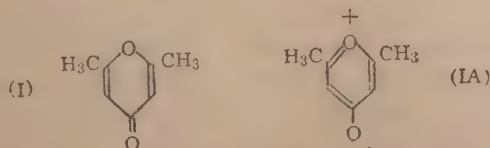
The discrepancies between the dipole moments of *p*-chlorophenol and *p*-bromophenol as determined by Williams (*Z. physik. Chem.*, 1933, B20, 175) and Donle (*ibid.*, 182) were shown to be due to their extrapolations to infinite dilution. When Hedestrand's method of computation was used, the discrepancies disappeared (Rau, *Physik. Z.*, 1933, 34, 575). Rau and Narayanaswamy suggested that the discordant values of the dipole moment obtained by various investigators from measurements in benzene solution were probably due to incorrect methods of calculating the molar polarization of the solute at infinite dilution. (*Z. physik. Chem.*, 1934, B26, 23, 32). They obtained the following values (\pm) 0.01 of $\mu \times 10^{-18}$:

Pyridine	2.26
α -Picoline	1.72

β -Picoline	2.30
γ -Collidine	1.93
Quinoline	2.16
Isoquinoline	2.54
α -Quinaldine	1.86
Piperidine	1.17
N-Methylpiperidine	0.91
Propylidene ethylamine	1.51

Rau found (*Proc. Indian Acad. Sci.*, 1935, 2A, 232) that the moment of tetralin (1 : 2 : 3 : 4-tetrahydronaphthalene), measured in benzene, is 0.5×10^{-18} , and not 1.66×10^{-18} as reported by Puchalik (*Acta phys. Polon.*, 1933, 2, 305), and he explained the small but finite moment by comparing tetralin with o-xylene.

The polarization of ethylene dibromide in four solvents (cyclohexane, carbon tetrachloride, toluene and benzene) at infinite dilution was determined (Rau and Narayanaswamy, *Proc. Indian Acad. Sci.*, 1934, 1A, 14). The moment by Debye's formula varied from 0.84 to 1.13 at 10°, and from 0.93 to 1.20 at 40°. The rise of moment with the temperature was due to the increased average variation from the *trans*-position. With the help of data on the $-\text{CH}_2\text{Br}$ group moment, the potential energies of the molecule in the *cis*-position in the four solvents at 20° were calculated as 29.4, 28.9, 24.5 and 18.6×10^{-14} ergs. The dipole moment of chloromethyl methyl ether in carbon tetrachloride was found to be 1.82, the value being explained by free rotation of the $-\text{CH}_2\text{Cl}$ group or by equilibrium between *cis*- and *trans*-isomers (Rau and Narayanaswamy, *Proc. Indian Acad. Sci.*, 1934, 1A, 217). Rau (*Proc. Indian Acad. Sci.*, 1936, 4A, 687) determined the dipole moment of 2 : 6-dimethyl- γ -pyrone (I) as 4.48, corresponding to 15 per cent of the ionic structure (IA).



Rau's value is likely to be more accurate than the value of 4.05 found by Hunter and Partington (*J. Chem. Soc.*, 1932, 2825). Coumarin has a moment of 4.51, while the calculated value for the normal covalent structure is 4.04, and Rau explained the small difference between the observed and calculated moment as the result of some of the excited phases being in the opposite sense to

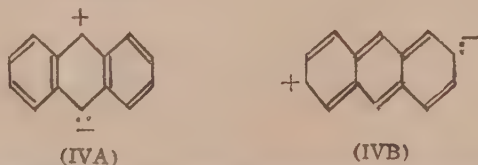
the normal value. Xanthone (II) was found to have a dipole moment of 2.93; by making allowance for the induction of the $C=O$ and $\rightarrow O$ moments in the benzene rings, the contribution of ionic structures such as (III) is found to be quite small and much lower



than in dimethyl- γ -pyrone. Rau explained this as being due to the unexcited resonance structures such as (IIA and B), many more of which can be written for xanthone than for dimethyl- γ -pyrone (see also Partington, *An Advanced Treatise on Physical Chemistry*, Vol. V, p. 464, Longmans, London, 1954).

The moments of phthalic, citraconic and succinic anhydrides, the first two in benzene and the last in dioxane as solvent, were found to be 5.25, 4.27 and 4.20×10^{-18} respectively (Rau and Ananthanarayanan, *Proc. Indian Acad. Sci.*, 1937, 5A, 185). The high value in comparison with the corresponding imides were interpreted in terms of resonance structures which reversed the normal direction of moment to be expected from vectorial addition.

By a comparison of the calculated dipole moments of the resonance structures (IVA) and (IVB) for anthracene, Rau and Venkataraman (*Curr. Sci.*, 1950, 19, 9) confirmed the suggestion of Jones (*J. Amer. Chem. Soc.*, 1945, 67, 2127; *Chem. Revs.*, 1947, 41, 353) that the short-wave high-intensity band in the absorption spectrum of anthracene is associated with an electronic transition polarized along the length of the molecule, and the long-wave low-intensity band is associated with a transition polarized across the width of the molecule.



The Sir Subramanya Ayyar Lectures for 1938-39 were delivered by Rau. They have been published as a monograph on

"Dipole Moments in Chemistry," which is a valuable contribution to the literature on induced and permanent electric moments, the reality of dipoles, methods of measuring dipole moments, solvent effect in dipole moment measurements, dipole-dipole and ion-dipole interactions, the relation between dipole moments and the structure of molecules, and the influence of dipole moments on chemical reactivity.

The diffraction patterns obtained with light that had traversed a system of superposed ultrasonic waves set up in a liquid showed the characteristic manner in which the number and intensities of the combinational lines depended on the intensities of the original spectral orders (Rau, *Proc. Indian Acad. Sci.*, 1938, 8A, 6).

A new case of Liesegang rings formation was observed during the coagulation of rubber latex (Verghese and Rau, *Curr. Sci.*, 1945, 14, 46). Periodic coagulation of rubber latex provides an example of the occurrence of periodicity in a colloidal system in the absence of a gel medium (Verghese and Rau, *J. Sci. Ind. Res.*, 1945, 4, 11). The number of stratifications obtained increases with increasing concentration of the colloid and salt solutions. The distance between consecutive rings increases in the direction of diffusion of the salt. These observations have been correlated with the polydisperse nature of the latex emulsion and the consequent differences in the mobility of the particles.

Rau's chemical engineering publications include the following: Pilot plants as a basis for the design of large scale equipment (*Curr. Sci.*, 1942, 11, 251); Method for designing packed columns (Simon and Rau, *Ind. Eng. Chem.*, 1948, 40, 93); Kinetics of absorption by chemically reacting solvent systems (Rau and Chandrasekharan, *Trans. Indian Inst. Chem. Eng.*, 1949, 1, 12); Rubber-lined equipment for chemical industries (Verghese, Rau and Ghosh, *J. Sci. Ind. Res.*, 1946, 5, 22).

One of Rau's many activities was to assist in the editorial and publication work of *Current Science*. Jointly with Mr. M. Sreenivasaya, the founder of *Current Science*, he was associated with this important journal throughout its life, and he was for many years the Secretary of the Current Science Association. He also wrote several reviews, among which may be mentioned: Molecular spectra (1934, 3, 78); Intramolecular rotation in organic compounds (1934, 3, 145); Dipole moments (1934, 3, 215); The carbonyl frequency in Raman spectra (1935, 3, 376); Heavy water

in chemistry (1935, 3, 384); The liquid state of matter (1937, 6, 139); Reaction kinetics (1938, 7, 82); Chemical reactions involving solids (1939, 8, 232); Hydrocarbon chemistry (1941, 10, 38).

He was one of the founders of the Indian Institute of Chemical Engineers and at the time of his death he was its Vice-President. He was a Fellow of the Indian Academy of Sciences. In the University of Madras he was Chairman of the Board of Studies in Technology and President of the Faculty of Technology. He was elected a Member of the Institution of Chemical Engineers, London, in 1951 and he was a member of its Indian Advisory Panel.

As a student in the Honours School of Chemistry at the Presidency College, Madras, and as a research worker under Professor H. E. Watson at Bangalore, Govinda Rau was known for his sound knowledge of mathematics, physics and chemistry, thoroughness of his experimental work, integrity of character, and very pleasant personality. He was at all times a giver, not a taker; and his students and colleagues at the Institute of Science, Bangalore, and the College of Technology, Madras, found this unusual quality in Govinda Rau throughout his life. When he turned from physical chemistry to chemical engineering in middle age, he studied the subject with characteristic thoroughness and enthusiasm, and in organizing the Department of Chemical Engineering at the Indian Institute of Science, Bangalore, and the College of Technology, Madras, he exhibited an unsuspected capacity for organization. The smallest detail concerning the drafting of a syllabus, ordering of a piece of equipment, or the difficulty encountered by a student in the lecture hall or laboratory was examined by him cheerfully and conscientiously. He was a born teacher, and till the day before his death, in spite of physical infirmities which afflicted him in the last years of his life, he placed himself unreservedly at the disposal of his students in tutorial classes and in the laboratory. The College of Technology at Madras possesses a Department of Chemical Engineering which is among the best in India. Govinda Rau has been in charge of the College of Technology since its inception, and the progress it has made during the brief period of ten years of its existence is due almost entirely to his single-minded devotion, strength of character, and his ability to obtain the confidence and affection of students and colleagues.

K. V.

Granitization of Charnockites in the Chalk Hills Region of Salem District *

BY

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(Received for publication, December 20, 1954)

ABSTRACT

The metamorphic history of the plutonic rocks of the Chalk Hills Region of Salem is discussed. Evidences are presented to show that the hornblende and biotite gneisses in the area have been formed by metasomatic granitization of the earlier granulite facies metamorphics (mainly the basic charnockites).

The area studied, about 50 square miles in extent, is located to the north of Salem town, South India. It is covered by the northern part of the Survey of India sheet No. 58 I/2, and is approximately between the parallels $11^{\circ} 39'N$ and $11^{\circ} 45'N$ and the longitudes $78^{\circ} 5'E$ and $78^{\circ} 10'E$.

A group of pre-Cambrian plutonic rocks, composed of pyroxene granulites, garnet-pyroxene granulites, pyroxenites (all these belonging to the charnockite series of Holland) and hornblende and biotite gneisses (Peninsular gneisses) are exposed in the area. Clearly intrusive into these rocks are certain basic and ultrabasic igneous rocks. To these latter groups belong the dunites (with extensive magnesite deposits) of Salem. The accompanying field map shows the field relationships.

General Statement

Rocks belonging to the charnockite series have been identified in the area by Holland (1900, 1901). He gives a detailed field and petrographical description of the various members of the 'charnockite suite' that outcrop in the Shevaroy massiff as well as in the smaller hills of the region. Holland (1901) considered the charnoc-

* Part of Thesis submitted to the University of Madras for the M.Sc. Degree. 1953.

PLATE I.



FIG. 1. Rims of garnet and diopside around hypersthene.
 FIG. 2. Rims of diopside around hypersthene.
 FIG. 3. Amphibolisation of diopside.
 FIG. 4. Amphibolisation of diopside.

clusions in the gneisses. He therefore believed that the charnockites were *post-deformational intrusions*. Later workers in the area (Aiyengar, 1943) have tended to follow the same line of thought.

As early as 1918, Vredenburg put forth the view that the charnockites represent the highly metamorphosed equivalents of the Dharwars. Rama Rao (1945) has confirmed, in part at least, this statement by his work on the Mysore charnockites. If, therefore, the identity, or at least the contemporaneity, of the charnockites with the Dharwars is accepted, it follows that the charnockites are older than the Peninsular Gneisses. And if the Peninsular Gneisses are not of magmatic origin, they must have been formed by the metasomatic granitization of closely related older rocks. The clue to the solution of this problem is therefore to be found in the mutual relationships of the charnockites and the Peninsular Gneisses. It is this aspect of the problem that is dealt with in this paper.

Rock Types and field relations

(a) *Charnockites*: The basic charnockites are dark grey to black in colour, and are generally medium grained, with local coarse grained segregations of pyroxenes. Typically they are composed of pyroxenes (both hypersthene and diopside) and plagioclase. But garnet is a common mineral, though sporadic in distribution, in this rock, and is often present as large porphyroblasts 3" to 4" in diameter. The garnetiferous varieties are roughly banded due to the concentration of a garnet in parallel bands. In some cases, the garnet free basic charnockites are also banded, the banding in this case being the result of alternation of feldspar-rich rock with feldspar-poor rock. These are different from the typical intermediate charnockites and resemble enderbitic gneisses.

The texture of the charnockites is typically xenomorphic granular (Plate I Fig. 2). Garnet is the only mineral showing any degree of crystal form, and even this mineral is quite often shapeless.

Plagioclase in the rock is normally twinned according to one law only, albite law. The absence of types of twins such as carlsbad, albite-carlsbad and manebach is significant as they are typical

of igneous rocks (Gorai, 1950). The composition as indicated by refractive index determinations is that of a basic andesine ($ab_{56} an_{44}$) in the basic types and tends towards oligoclase in the intermediate types. Twinning lamellae are consistently bent and the grains show undulose extinction.

Diopside predominates over hypersthene, and is of a light green colour with $2V_z - 59^\circ$ and $c\Delta Z - 45^\circ$.

Hypersthene is strongly pleochroic with X—pink, Y—yellow and Z—Green (with a bluish tinge). It generally alters readily to a fibrous wispy aggregate, although the associated diopside is often fresh. $2V_x$ varies from 64 to 66. Both the pyroxenes are sometimes seen in parallel growth, but often there is evidence to show that the diopside has formed from the hypersthene. In the latter case, a rim of diopside is seen around hypersthene (Plate I Fig. 2).

Hornblende showing pleochroism from brownish green, green to yellow is present in some of the basic varieties. There is no evidence in some of these types to show that it is formed from the pyroxenes; the hornblende appears to be in stable equilibrium with the pyroxenes.

In the garnetiferous varieties, the different stages in the formation and development of garnet can be clearly defined. Garnet starts forming as a thin rim around diopside or hypersthene at their margins with plagioclase (Plate I Fig. 1). Large crystals of garnet enclosing blebs of diopside or hypersthene, show that these too have grown by reaction of the pyroxenes with plagioclase. In many cases hypersthene has a thin rim of diopside around which there is another rim of garnet (Plate I Fig. 1). There is enough evidence, therefore, to show that garnet, which is not an original constituent of the basic charnockites, grows in the rock by metamorphic reaction at the expense of pyroxenes and plagioclase. Secondary plagioclase and quartz, released during these mineral transformations, occur as vermicular inclusions in the garnets. Inclusions of iron ore also are common. The garnet is pink, and its colour resembles that of hypersthene in favourable orientations.

Holland (1901, p. 101), while describing the principal occurrences of the charnockite series, states that "near the south-west foot of the Shevaroyis, and again between Salem town and Kanjamalais,

small, bare, rocky hills stand up abruptly above the general level of the plain. Some of these are clearly lenticular in structure, and consist of masses of basic, garnetiferous members of the charnockite series." Holland notes that "the lenses vary in size from a few inches to small hillocks . . . and through larger hills to mountain masses like the Shevaroyes." According to the same authority, "other masses of basic types (norites) without garnets occur as lenses of all sizes in the *leaf gneisses* (Peninsular Gneisses) of the Salem-Ahtur valley."

The present work confirmed Holland's field observations. It was further possible to extend their scope and to observe both in the field and in thin section the marginal facies of these lenses and bands of charnockites in the gneisses. Foliation and lineation, wherever present, in the charnockites are parallel to those in the gneisses. The long axes of these lenses, and the bands, are parallel to the foliation of the gneisses. Nowhere was any discordant contact between the two types noted.

It is evident from the foregoing that the charnockites which outcrop in the area, occur as lenses and bands of varying sizes in the hornblende-biotite gneisses (Peninsular Gneisses), and that there is significant parallelism both in the dimensions of the bands and lenses, and in the megascopic fabric of the charnockites to the structural features in the gneisses.

The lenses and bands of basic charnockites do not have sharp boundaries with the gneisses. On the contrary, there is a quick but gradual transition from one rock to the other. The basic charnockites in the lenses are, near their margins, veined by (white) quartzo-feldspathic material. This migmatization of the charnockites is increasingly evident from the interior of these lenses, until, at the margins with the gneisses, the rock passes imperceptibly into garnet hornblende gneisses and hornblende gneisses. The passage from the charnockites to the biotite-hornblende gneisses is thus seen to be very gradual. This gradational character of the migmatized charnockites in the field is reflected in a gradual change in the mineralogical composition which can clearly be observed in thin sections (see below). On the basis of field evidence it is therefore more logical to consider the charnockites as 'inclusions' rather than as 'intrusions', in the gneisses.

(b) *Transitional varieties to hornblende gneisses*: The transitional rocks between the charnockites (pyroxene and garnet-pyroxene granulites) and the hornblende-(biotite) gneisses are the garnet-pyroxene-hornblende-(biotite) gneisses. These are characterised by a heterogeneity in structure and in the mutual proportions of the various minerals. They range from garnet-pyroxene gneisses with subordinate amounts of hornblende and biotite, through garnetiferous hornblende-biotite gneisses with minor amounts of pyroxenes, to hornblende-biotite gneisses with rare garnet and pyroxenes.

The garnet-pyroxene-hornblende-biotite gneisses are banded rocks; they are truly migmatitic. In the early stages of migmatisation (near the interior of these lenses of charnockites) the rock is a garnet-pyroxene granulite (typical basic charnockite) veined by (white) quartz-feldspar. Away from this zone, the size and number of the quartzo-feldspathic veins increase, and the bands of garnet-pyroxene-hornblende granulite get broken up into lenses and boudins, until finally the rock grades into a more or less homogeneous hornblende-biotite gneiss with stray streaks of mafic minerals.

Specimens were collected of this transition series from the pure, unaltered basic charnockites to the hornblende gneiss. Thin sections of these critical rocks showed the mineral transformations that characterise the series and the change in the mutual proportion of the different minerals.

Garnet, pyroxenes (both diopside and hypersthene), hornblende, small amounts of biotite, epidote, plagioclase and quartz comprise the mineral assemblage of the migmatised charnockites. All these minerals are present in varying proportions and planimetric analysis of these rocks show the gradational quantitative change in the proportion of these minerals, from the interior to the margin of the lens of charnockite. It shows the change in the mineralogical character of the rock with progressive migmatisation. The results of the modal analyses (volume percentages) are given in Table I.

TABLE I

	I	II	III	IV
Diopside	.. 36.45	31.52	10.32	16.39
Hypersthene	.. 12.70	12.59	7.45	—
Garnet	.. —	14.38	14.82	—
Plagioclase	.. 47.78	35.82	50.90	28.84
Hornblende	.. 1.20	2.45	15.46	29.14
Biotite	.. 0.40	—	0.75	—
Ore	.. 1.31	2.90	0.05	2.22
Apatite	.. 0.18	—	—	—
Quartz	.. —	—	—	0.36
Epidote	.. —	—	0.29	15.21

I—Basic charnockite (pyroxene granulite).

II—Garnetiferous basic charnockite.

III—Garnet-pyroxene-hornblende gneiss.

IV—Garnet-hornblende-pyroxene-epidote gneiss; (the specimen analysed was free from garnet).

The analysis shows that with increasing migmatization the pyroxenes tend to become quantitatively less important with a concomitant increase in the proportion of hornblende and epidote. Quartz does not become a major constituent in these rocks; it increases appreciably only in the completely migmatized rocks, such as the banded or homogeneous hornblende gneisses. Garnet is absent in the typical basic charnockite and is formed by reaction of pyroxenes with plagioclase in the garnetiferous varieties. This is one of the first changes that affect the mineral assemblage of the charnockites. In the final stages of migmatization, however, even garnet tends to disappear from the assemblage.

The mineralogical transformations observed in these rocks are interesting and even more convincing than the features noted previously. Undoubted examples of the conversion of diopside and hypersthene (and garnet) to bluish green hornblende are common, and all the stages in this transformation can be observed (Plate I Figs 3 and 4). Basic plagioclase in the charnockites gets progressively acidified (from $ab_{56} an_{44}$ to $ab_{63} an_{37}$). Concomitant with this acidification of plagioclase, epidote forms in quantity in the rock. Plagioclase grains studded with small, fresh formed

epidote are clear evidences of this. Sections of the most highly migmatised rocks show that these replacement reactions have proceeded nearly to completion; only small relict grains of garnet and diopside are present, hypersthene having been completely replaced by diopside and garnet in the initial stages, and by bluish green hornblende in the final stages.

The results of the modal analyses presented in the Table I, shows that with increasing migmatisation there is a distinct change in the mineral (as well as chemical) composition of the rocks. Metasomatism, therefore, has played an equally important part as metamorphic recrystallisation in this process of conversion of the basic charnockites to the gneisses. The bluish green colour of the hornblende in the migmatised rocks is probably indicative of soda-metasomatism. The progressive acidification of the plagioclase, and the entry of quartz into the assemblage are also indicative of metasomatism. The microscopic evidences prove that the charnockitic minerals are being destroyed in the transitional rocks to the hornblende gneisses, and that the nett result of these alterations is the production of a mineral assemblage characteristic of the Hornblende-biotite gneisses. All the gradational varieties between the charnockites and the gneisses are present. The microscopic observations fully confirm the deductions made on the basis of field data.

(c) *Migmatitic hornblende-biotite gneisses*: These rocks are generally light coloured, banded rocks. The basic bands, lenses, boudins and clots are composed of hornblende with minor amounts of epidote and plagioclase. Plagioclase with small quantities of quartz form the main minerals in the light bands. Intricate folding of the quartzo-feldspathic bands on a small scale is evident even in a hand specimen. The feldspathic as well as the hornblendic bands are impersistent. Hornblende and plagioclase are the predominant minerals in the rock. Biotite, whenever present, occurs in variable quantities, and to an extent replaces the earlier hornblende. Varying amounts of epidote are present, and, in some types, appear to be in stable equilibrium with the plagioclase. However, in certain other types, replacement of plagioclase by epidote, and the consequent formation of more acid plagioclase, shows that epidote and basic plagioclase are not always in equilibrium in the rocks. Plagioclase is mostly untwinned, and the composition is that of a basic oligoclase— $ab_{63}an_{37}$. The hornblendes in the gneisses have characteristic pleochroism in strong tones of bright bluish green (Z),

green (Y) and pale yellow (X). $2V_x$ varies from 70° to 72° . The other optical constants are :

$$N_z = 1.6798 \pm 0.0005; N_x = 1.6623 \pm 0.0005;$$

$$N_z N_x = 0.0175; Z\Delta c = 24^\circ.$$

Epidote forms rounded grains with irregular margins. As already stated, plagioclase grains studded with small grains of epidote are seen. Apatite rimmed with grains of epidote are also seen. Epidote has $2V$ of 80° indicating that approximately 18% of $\text{HCa}_2\text{Fe}_3\text{Si}_3\text{O}_{13}$ are present (Winchell, 1951). Iron ore occurs as irregular masses and also as oriented lamellae in the cleavages of biotite.

Though considerable variation in the mutual proportions of these minerals exists, the minerals themselves vary only slightly in their properties.

Metamorphic Facies

A short resume of the field and petrographic characters discussed in the previous pages will be pertinent in an inquiry into the status of the rocks just described in the facies system.

The basic charnockites of the area occur as thin bands and lenses in the migmatitic hornblende-biotite gneisses. These charnockites show varying degrees of migmatisation (by white quartzofeldspathic veins) and alteration to rocks resembling in structure and mineralogy the hornblende gneisses. Such migmatisation is found to increase in intensity towards the margins of the bands and lenses of charnockite.

A study of the thin sections of the basic charnockites, the transitional rocks to the hornblende gneisses (the pyroxene-hornblende gneisses), and the hornblende gneisses shows that the progressive migmatisation of the basic charnockites (as observed in the field) is accompanied by certain critical mineral transformations. The formation of garnet from pyroxenes, of brownish and bluish green hornblende from pyroxenes and garnet, and the acidification of basic plagioclase (with the consequent development of epidote in the rocks) are some of the more important reactions. The significance of these from the facies standpoint will be discussed now.

The typical pyroxene granulites, the basic charnockites (as has been described in the foregoing sections), consist of diopside, hypersthene and plagioclase. This mineral assemblage, and the granulitic texture of the rock, are characteristic of the granulite facies (Turner, 1948, p. 101). The basic members of the charnoc-

kite series have this mineral association, and it is supposed that they have been formed under the conditions of the granulite facies (Muthuswami, 1953; Eskola, 1952; Quensel, 1951).

There is no evidence in the area to suggest the original mineral assemblage from which the association, diopside-hypersthene-plagioclase was formed in the basic charnockites. All the mineral transformations described in the previous section are directed towards the development of new minerals, replacing the typical granulite facies assemblage, diopside-hypersthene-plagioclase.

The development of garnet in some basic charnockites is significant in this respect. Garnet is formed by reaction between diopside or hypersthene with plagioclase (Holland, 1896; Groves, 1935; Ghosh, 1941; Muthuswami, 1951, 1953; Ramachandran, 1952). Garnet forms as a thin rim around diopside and hypersthene at their contacts with adjacent plagioclase grains. Successive rims of diopside and garnet around hypersthene are also seen. According to accepted petrographic criteria of equilibrium, "disequilibrium is recognisable where one mineral is obviously in the process of replacement by another.." (Turner, 1948, p. 56). Furthermore, rocks in which garnet is associated with diopside, hypersthene and plagioclase do not strictly conform to the granulite facies (Turner, *op. cit.*, p. 101, fig. 31). The garnet-diopside-hypersthene-plagioclase association seen in the garnetiferous basic charockites are therefore signs of readjustment to changed conditions. The garnetiferous pyroxene granulites (basic charnockites), which have the above non-equilibrium assemblage, are therefore to be considered as transitional between the granulite facies proper (as represented by the typical garnet-free basic charnockites), and the almandine-diopside-hornblende subfacies of the amphibolite facies as represented by the garnet-pyroxene-hornblende gneisses.

Some of the basic charnockites contain in addition to the normal assemblage, brownish hornblende. In such of those rocks where no evidences of the replacement of pyroxenes by hornblende are found, hornblende is probably in equilibrium (Turner, 1948, p. 102). Usually however, clear evidences are present to show that hornblende is secondary after the pyroxenes (Plate I, Fig. 3). Thus a transition from the granulite facies to the almandine-diopside-hornblende subfacies of the amphibolite facies is indicated.

The garnet-pyroxene-hornblende (biotite) gneisses, the transitional rocks to the hornblende gneisses, have typically non-equilibrium assemblages. Every stage in the replacement of diopside,

hypersthene and garnet by bluish green hornblende (and biotite) is seen in thin sections of these rocks. With increasing migmatisation, the pyroxenes disappear from the assemblage, and the rock grades to a garnetiferous hornblende gneiss. The transition to the amphibolite facies is thus complete.

The evidences presented show that the charnockites represent rocks of the highest metamorphic grade in the area. The formation of garnet and brown hornblende in them is the result of adjustment to lowered metamorphic conditions. It is the result of deep-seated diaphthoresis. With the onset of migmatisation (under amphibolite facies conditions), garnet-pyroxene-hornblende gneisses, garnet-hornblende gneisses, and hornblende gneisses are formed.

Conclusions

The metamorphic history of the area can be summarised as follows :

(1) Metamorphism of a composite series of rocks under conditions of the granulite facies to form the basic charnockites and pyroxenites.

(2) Retrograde metamorphism and metasomatic granitization of the charnockites under lower metamorphic conditions, conditions of the amphibolite facies, resulting in the formation of the transitional garnet-pyroxene-hornblende gneisses and finally the migmatitic hornblende gneisses (Peninsular Gneisses).

The dunites, peridotites, mica-peridotites, picrites and dolerites of the area are post-metamorphic (and post-granitization) *intrusives*. Their contacts with the charnockites and the gneisses are discordant and most often sharp. In a few cases, metamorphic differentiation, accompanying the hydrothermal metamorphism (which formed the magnesite deposits) of the dunite has blurred the contacts and zones of talc, actinolite and chlorite schists are developed at the margins of the dunite plugs. These intrusives have no genetic relationship with the charnockites and the gneisses (Narayanan, 1953). It has been suggested (Pichamuthu, 1953) that the charnockites were formed by progressive metamorphism of a higher grade of the adjoining gneisses. The mineral transformations observed by the present writer in sections of specimens collected serially from the charnockites to the gneisses (both along and across the strike) do not support such an hypothesis. On the contrary, there is every evidence to show that the charnockites

underwent retrograde metamorphism and metasomatic granitization resulting in the formation of the hornblende/biotite gneisses.

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Two Amphiboles from the Anorthite and Biotite Gneisses of Sittampundi—Salem Dt.

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ABSTRACT

An amphibole from anorthite gneiss and another from an adjoining biotite gneiss have been chemically analysed and their optical characters determined. Their chemical and optical relationships to other analysed amphiboles are discussed.

Anorthite gneisses have been reported from Sittampundi, Tiruchengode Taluq, Salem Dt. (Middlemiss, 1896). A characteristic blue amphibole occurs in these gneisses. Also a greenish-blue amphibole characterises the biotite gneisses adjoining the anorthite gneiss.

The anorthite gneiss, under the microscope has a granulitic texture. The rock is composed of amphibole and anorthite, but sometimes pure amphibole portions occurring as veins and lenses are also met with. The amphibole under study has been taken from one such concentration near Pamandampalayam (a village near Sittampundi). The hand specimen is dark green in colour and is schistose. It is acicular in habit. The fact that it is well orientated is also noticed in the microslides, since the optic axial angle measured directly is always the obtuse angle. The average grain size ranges from 3.6×1.6 mm. to 0.22×0.14 mm. The anorthite content of the plagioclase feldspars in the anorthite gneiss ranges from 85-95%.

The biotite gneiss has schleiren of amphibole and biotite. The schleiren are hard, compact, dark-looking, coarse grained rocks having segregated plates of amphibole and flakes of biotite. The dimensions of the largest and smallest grains of amphibole are 5.6×3.3 mm. and 0.12×0.06 mm. respectively. The anorthite content of the plagioclase feldspars in the biotite gneiss ranges from 25-30%.

TABLE I

No. 1	Wt. %	Mol. Prop.	Oxygen atoms	Metal atoms	Basis 24 (O, OH, F)	
SiO ₂	45.91	0.7650	1.530	Si-0.765	6.633	8.00
Al ₂ O ₃	18.25	0.1790	0.537	Al-0.358	3.103	1.367
TiO ₂	0.05	0.0005	0.001	Ti-0.001	0.009	1.736
Fe ₂ O ₃	—	—	—	Fe'''—	—	
FeO	6.07	0.0840	0.084	Fe''-0.084	0.728	
MnO	0.08	0.0010	0.001	Mn-0.001	0.009	5.116
MgO	12.10	0.3030	0.303	Mg-0.303	2.625	
Cr ₂ O ₃	0.05	0.0005	0.001	Cr'''-0.001	0.009	
CaO	15.42	0.2750	0.275	Ca-0.275	2.382	
Na ₂ O	0.32	0.0050	0.005	Na-0.010	0.087	2.478
K ₂ O	0.05	0.0005	0.001	K-0.001	0.009	
H ₂ O+	0.54	0.0300	0.030	OH-0.060	0.520	
H ₂ O—	0.15	0.0090	—	—	—	
F	0.02	—	—	—	—	
Less O for F	0.01	—	—	—	—	
Total	99.00		2.768	1.859		

$$F = 24/2.768 = 8.670$$

No. 2	Wt. %	Mol. Prop.	Oxygen atoms	Metal atoms	Basis 24 (O, OH, F)
SiO ₂	43.91	0.732	1.464	Si-0.732	6.362
Al ₂ O ₃	19.04	0.186	0.558	Al-0.372	3.232
TiO ₂	0.89	0.011	0.022	Ti-0.011	0.239
Fe ₂ O ₃	—	—	—	Fe'''- —	—
FeO	8.65	0.120	0.120	Fe''- 0.120	1.206
MnO	Tr.	—	—	Mn —	—
MgO	12.96	0.324	0.324	Mg 0.324	2.816
CaO	12.13	0.217	0.217	Ca 0.217	1.887
Na ₂ O	1.29	0.021	0.021	Na 0.042	0.365
K ₂ O	0.17	0.002	0.002	K 0.004	0.034
H ₂ O +	0.60	0.033	0.033	OH 0.066	0.574
H ₂ O —	0.11	0.006	—	—	—
Total	99.75	—	2.761	1.888	—

$$F = 24/2.761 = 8.692$$

} 1.638
 } 1.594
 } 8.00
 } 5.855
 } 2.286

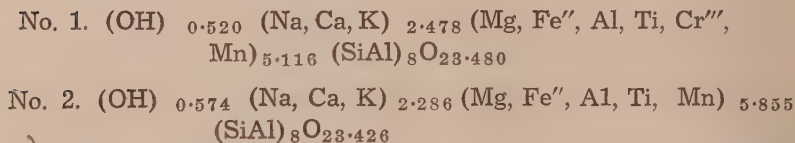
These two amphiboles have been chemically analysed and their optical characters determined. The results are presented in this paper.

The chemical analyses are given in Table I.

No. 1 refers to the amphibole in anorthite gneiss and No. 2 to the amphibole in biotite gneiss.

The total of analysis No. 1 is only 99.00. The deficiency in the total is probably due to the defective determination of water. Water was determined by loss on ignition in a Muffle Furnace. The chemical analyses do not correspond to those in published literature—especially in the content of alumina. It is also noticed that ferric iron is typically absent in these amphiboles.

Warren's formula for the two amphiboles is as follows:—



Berman (1937) has given a classification of the amphiboles on the basis of the following ratios:—

X	Y	Z = Si : Al	Species
5	0	7 : 1	Hornblende-Edenite
4	1	6 : 2	Hastingsite
3	2	8 : 0	Glaucophane
4	1	8 : 0	Arfvedsonite

X = Mg, Fe'', Mn'' Y = Al, Fe''', Ti

Z = Si, Al in ratios given above

W = Ca, Na, K.

The calculated W, X, Y and Z values for the two amphiboles are given below :

	W	X	Y	Z = Si : Al
No. 1	2.478	3.362	1.745	7 : 1
No. 2	2.286	4.022	1.833	6 : 2

Amphibole No. 1 has the ratio X : Y as 3 : 2 and Z = Si : Al as 7 : 1 nearly. Therefore, in the Si : Al ratio it corresponds to Hornblende-Edenite, and in X : Y ratio to Glaucophane. Amphibole No. 2 has the ratio X : Y as 3 : 2 and Z = Si : Al as 6 : 2.

Therefore in the X : Y ratio it corresponds to Hornblende-Edenite and in the Si : Al ratio to Hastingsite.

Sundius (1946) and Winchell (1945) have discussed the various molecules present in amphiboles. The chemical analyses of the amphiboles under study have been calculated in terms of these molecules. The molecules and amounts present are given below :

Amphibole	Ed.	Fe. Ed.	Ts.	Fe. Ts.	Ha.	Fe. Ha.	Ca (Mg, Fe) Si ₂ O ₆	Ku.	Gr.
No. 1	6.76	1.98	57.46	15.95	—	—	17.96	—	—
No. 2	—	—	34.52	12.79	22.83	8.47	—	5.50	2.04

Ed = Edenite

Fe. Ed = Ferro-edenite

Ts = Tschermakite

Fe. Ts = Ferro-tschermakite

Ha = Hastingsite

Fe. Ha = Ferro-hastingsite

Ku = Kupferite

Gr = Grunerite

The molecules present in both the amphiboles are Tschermakite and Ferrotschermakite. Edenite, Ferro-edenite, and the hypothetical metasilicate Ca (Mg, Fe) Si₂O₆ are present in No. 1 while Hastingsite, Ferro-hastingsite, Kupferite, and Grunerite molecules are present in No. 2.

Since the chief variation in calciferous amphiboles is in the relative content of (Ca, Na, K) (Mg, Fe'') and (Al, Fe''') atoms, these atoms are plotted in a trilinear variation diagram (Fig. 1).

The figure also includes points plotted from Hallimond's (1943) data. The calciferous amphiboles lie in a band between (Ca, Na, K) 25 and 35. Many points of Hallimond's data lie near the plots for the analysed amphiboles. Particularly Nos. 134, 169, 172, 175, and 179 (Hallimond 1943) lie near to No. 1 and 114, 129, 170 and 185 (Hallimond 1943) lie near to No. 2. But the paragenesis of amphiboles corresponding to these numbers as given by Hallimond are different. Numbers corresponding to No. 1 of the analysed amphibole are either hastingsite or basaltic hornblende occurring in igneous rocks and numbers corresponding to No. 2 of the analysed amphibole are hornblendes, pargasite or basaltic hornblendes occurring in schists, pegmatites or granulites.

Buddington (1950 & 1952) has studied the pyroxenes and hornblendes of Adirondack and states that the pyroxenes of the

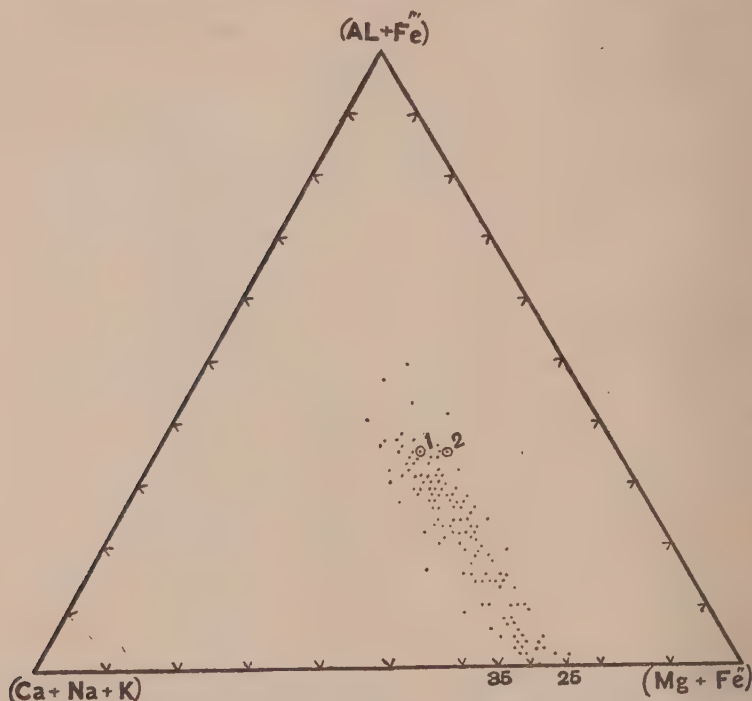


FIG. 1. (Ca, Na, K), (Al + Fe''), (Mg + Fe'') diagram;

1 = Amphibole from anorthite gneiss, Sittampundi.

2 = Amphibole from biotite gneiss, Sittampundi.

anorthosite gneiss are unusually rich in alumina owing to the different environment in which they were formed. The unusual amount of alumina present in the amphiboles here analysed is also possibly due to a similar association. Owing to the same cause analysis No. 1 (occurring in anorthite gneiss) has more CaO than No 2 (occurring in biotite gneiss) and No. 2 has more MgO and iron than No. 1.

The optical characters of the analysed amphiboles are as follows:—

No. 1	No. 2
$\alpha = 1.616$	$\alpha = 1.619$
$\beta = 1.625$	$\beta = 1.644$
$\gamma = 1.636$	$\gamma = 1.659$
$+ 2V = 83^\circ \text{ to } 87^\circ$	$- 2V = 71^\circ \text{ to } 72^\circ$
85° (Average of 13 readings)	71° (Average of 6 readings)

Z \wedge C = 18°	Z \wedge C = 20°
(Average of 5 readings)	(Average of 3 readings)
Y = b	Y = b
$\rho > v$	$\rho > v$
Pleochroism	Pleochroism
X = Light Yellow	X = Yellow
Y = Light Green	Y = Brownish Green
Z = Light Blue	Z = Bluish Green
Sp. Gr. = 3.148	Sp. Gr. = 3.187
V = 276	V = 273

Seitsaari (1953) has reviewed the literature on the colour of hornblendes and comes to the conclusion that the blue-green tinge is due to the $\text{Fe}_2\text{O}_3/\text{FeO}$ ratio and possibly the water content. In the analysed amphiboles Fe_2O_3 is absent and since the determination of water has been defective no conclusion can be drawn from its relative abundance. It appears that the presence of Kupferite and Grunerite molecules, in other words, the excess of magnesia and iron, is responsible for the appearance of brownish and greenish tints and deeper tints of blue in No. 2, whereas the presence of Edenite molecule accounts for the paler tints of No. 1. Alumina is about the same in both the amphiboles and no role can be assigned to it, from the point of view of colour.

The Niggli Basis for the two amphiboles are as follows:—

	Amp. No. 1	Amp. No. 2
Kp	0.17	0.66
Ne	1.67	6.92
Cal	28.94	26.83
Cs	8.52	4.45
Fo	25.92	26.67
Fa	7.01	9.88
Ru	0.06	0.61
Q	28.34	23.98
Q	28.34	23.98
L	30.78	34.41
M	40.88	41.61

The Q, L, M values are plotted in the Niggli (1945) diagram (Fig. 2). Both the points lie beyond the field of amphiboles of Eruptive rocks.

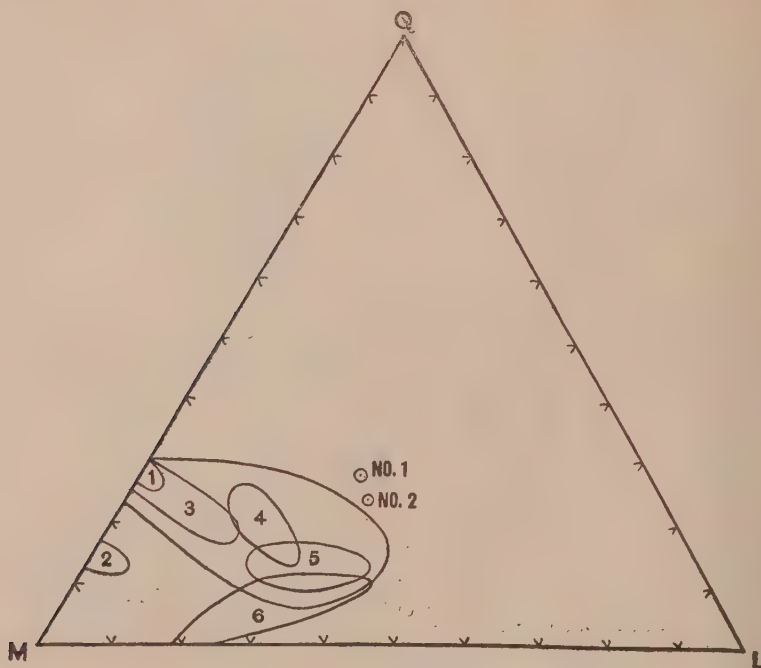


FIG. 2. Niggli's Q, L, M diagram of important amphiboles and melilites of eruptive rocks :—

1. Grunerite and Altered hornblendes.
 2. Aenigmatite.
 3. Alkali hornblendes.
 4. Common hornblendes.
 5. Barkavikite, Hastingsite, Basaltic hornblendes.
 6. Melilite.
- No. 1: Amphibole from anorthite gneiss, Sittampundi.
No. 2: Amphibole from biotite gneiss, Sittampundi.

Nomenclature

Both the analysed amphiboles are calciferous, aluminous amphiboles. As remarked above they do not fit exactly into Berman's classification.

Winchell (1951) makes a distinction between calciferous amphiboles as Pargasite and Common Hornblende, the former having a positive optic axial angle and the latter a negative optic axial

angle. On this basis the amphibole of the anorthite gneiss should be regarded as having affinity to Pargasite and the amphibole of the biotite gneiss as Common Hornblende.

The analyses are compared below to nearly similar analyses of amphiboles found in literature:—

	Amp. No. 1	Amp. No. 2.	A	B
SiO ₂	45.91	43.91	43.50	45.28
Al ₂ O ₃	18.25	19.04	13.15	9.20
TiO ₂	0.05	0.89	1.12	0.46
Fe ₂ O ₃	—	—	3.39	5.85
FeO	6.07	8.65	9.38	9.65
MnO	0.09	Tr	0.09	0.24
MgO	12.10	12.96	14.25	12.93
CaO	15.42	12.13	10.58	12.82
Na ₂ O	0.32	1.29	2.53	0.64
K ₂ O	0.05	0.17	0.68	0.42
H ₂ O +	0.54	0.60	1.15	2.68
H ₂ O—	0.15	0.11	0.12	0.00
Cr ₂ O ₃	0.05	—	—	—
F	0.02	—	0.30	—
Total	99.01	99.75	100.24	100.17
Less O for F	0.01	—	0.12	—
Total	99.00	99.75	100.12	100.17
2V	+ 85°	—71°	+85°	—68° to —70°

Ratio. Mol. Percent. CaO, MgO, FeO+MnO.

CaO	41.5	32.8	28.0	31.8
MgO	45.7	49.1	52.5	44.8
FeO+MnO	12.8	18.1	19.5	23.4

Amp. No. 1—Amphibole from Anorthite Gneiss, Sittampundi, Salem Dist., Analyst: C. E. Nehru.

Amp. No. 2—Amphibole from Biotite Gneiss, Sittampundi, Salem Dt., Analyst: C. E. Nehru.

A—Amphibole from Pyralmandite amphibolite, Adirondack—No. 10, Table III, Buddington (1952); Analyst: S. B. Levin.

B—Amphibole from Hornblende Schist, Northwest of Lake Pappilanselkä, Orivesi, No. 5 of Seitsaari (1953); Analyst: A. Juurinen.

Seitsaari (1953) regards his amphibole No. 5 as having affinity to Pargasite but gives a negative optical axial angle and Buddington (1952) calls amphibole No. 10 of his analyses as just hornblende but gives a positive optic axial angle. The ratios of CaO, MgO, (FeO + MnO) have been calculated for the three hornblendes and compared with ratios given by Buddington (1952). The amphibole No. 2 of the Biotite gneiss corresponds to hornblende of Buddington and Pargasite of Seitsaari, whereas, the amphibole No. 1 of the anorthite gneiss does not correspond to this ratio. It is, therefore, difficult to name on chemical grounds which of the analysed amphiboles is Pargasite and which not, and the problem of nomenclature of calciferous amphiboles remains unsolved.

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Vogesites and Noritic Olivine Dolerites from Salem and Dodkanya

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ABSTRACT

Five dyke rocks, two from Salem and the rest from Dodkanya, Mysore, have been chemically analysed and the optical characters of their minerals investigated. The dykes of Salem (Vogesites) seem to be related to a shonkinitic magma while those of Mysore (noritic olivine dolerites) are related to a gabbroid magma.

Introduction

The occurrence of doleritic dykes in Salem and Mysore have been reported by Holland (1897) and Rama Rao (1926) respectively, but no detailed optical and chemical work on them are on record. Besides these, dyke rocks of lamprophyric character from Salem and of a gabbroic type from Mysore have been observed by the author. A map of the rock types of the areas is under preparation. This paper deals with a detailed report of the chemical characters of these dyke rocks and an optical study of their mineral assemblages.

In the first part, the dyke rock of doleritic type from Salem and its petrochemical relationships are discussed. In the second part, the lamprophyre dyke of Salem and its relationship with the shonkinitic magma is dealt with. In the third part, the doleritic and gabbroic dykes of Mysore are studied. Lastly, an attempt is made to compare the dyke rocks of the two areas.

PART I

Fine-grained dolerite from Salem

A very fine grained dolerite dyke, about fifty yards wide, is known to occur in the magnesite areas of Salem, extending NE-SW

from Chengaradu to Δ 1503. (Lat. $11^{\circ}44'$ — $11^{\circ}45'$ — Long. $78^{\circ}7'$ — $78^{\circ}8'$. 58 I/2). Megascopically, it looks like a hard, dark-coloured, very fine-grained and fairly fresh-looking rock.

In thin section (Plate I, 1) the rock is found to consist of laths of plagioclase ($\cdot96 \text{ mm} \times \cdot44 \text{ mm}$ to $\cdot06 \text{ mm} \times \cdot06 \text{ mm}$), which are invariably bigger in grain size than the pyroxenes. The mafic minerals include augite ($\cdot96 \text{ mm} \times \cdot80 \text{ mm}$ to $\cdot04 \text{ mm} \times \cdot04 \text{ mm}$) hypersthene ($\cdot12 \text{ mm} \times \cdot10 \text{ mm}$ to $\cdot04 \times \cdot04 \text{ mm}$) and hornblende ($\cdot30 \text{ mm} \times \cdot24 \text{ mm}$ to $\cdot06 \text{ mm} \times \cdot06 \text{ mm}$) together with minor amounts of biotite and iron-ore. The texture is fine-grained, hypidiomorphic and resembles the texture of a basalt. No ophitic texture is seen. There is no glass.

Mineralogy

Felspars: Plagioclases are mostly twinned. Sometimes they give a check-pattern resembling microcline, due to Albite and Pericline striations. The plagioclase grains exhibit a tendency to granulation, though it is well seen among the pyroxenes. They tend to occur in glomeroporphyritic groups. A few occasional grains are zoned and a few others are clouded. The zoned plagioclase grains do not show any notable difference in the anorthite content of the different zones. In some grains, minute inclusions are arranged parallel to (001) and give the appearance of basal cleavage.

The results of determination of twin-laws on these plagioclase grains are given in Table I. The ratio of complex to simple laws is 7:3 nearly. The anorthite content of the grains varies from 40 to 55%, the majority of them giving about 50%. The normative composition of the plagioclase is also $\text{Ab}_{50} \text{An}_{50}$.

Pyroxenes: The pyroxene grains are subhedral to anhedral and well granulated. Twinned grains are not seen. The augite is light green in colour and some grains are completely replaced by hornblende. A few augite grains show lamellar appearance.

The optical characters are :

$$+2V = 55^{\circ} - 60^{\circ} \text{ (measured on 21 grains).}$$

ZAC = 41° (measured with reference to (110) cleavage trace).

$$\gamma - \alpha = \cdot022, \quad \gamma - \beta = \cdot017, \quad \beta - \alpha = \cdot005.$$

TABLE I

Rock Type	An-content	No. of grains determined	Normal Law			Parallel Law			Complex Law					Percentage of complex and parallel to simple law		
			Albite	Manebach	Baveno-right	Baveno-left	Carlsbad	Akline=Manebach-ala	Periclina	Ala	Albite-ala	Albite-carlsbad	Combined Albite-Periclina		Combined Albite-carlsbad	Combined Carlsbad-Periclina
R. 45 Fine-grained dolerite, Salem.	40-55% ground-mass 40-50%	36	11	—	—	—	14	—	—	—	11	5	3	4	1	69%
D. 7 Olivine-dolerite, Dodokanya.	45-70%	27	3	—	2	—	8	3	—	—	11	3	1	—	2	81%
D. 16 Olivine-dolerite, Dodokanya.	40-70% ground-mass 55-65%	30	12	—	—	—	10	3	—	—	5	5	1	2	1	60%
D. 58 Gabbroic-dyke, medium grained.	45-70%	30	15	—	—	—	7	3	—	—	1	4	1	6	2	50%
D. 67 Gabbroic-dyke Coarse-grained.	40-65%	20	7	—	—	—	6	3	—	—	1	9	4	5	4	65%
Total	..	143	48	—	2	—	45	12	—	—	2	34	25	11	12	10

There are also granular pieces of hypersthene which are at times lamellar showing pleochroism from green to brownish red. X = green. Y = brown. Z = brownish red. The other optical characters are :

$-2V = 47^\circ - 51^\circ$ (measured on 30 grains).

$\beta = 1.718-1.722$, $\gamma - \alpha = .013-.015$, $\beta - \alpha = .011-.012$

The clinopyroxene has got a composition $Wo_{51} En_{25} Fs_{24}$ and the orthopyroxene $En_{52} Fs_{48}$, as re-calculated from the norm. These seem to agree closely with the observed optical characters (Muir, 1951, Poldervaart, 1947).

Hornblende : The hornblende occurs both as an alteration product of augite and also as a primary mineral.

X = light green. Y = green. Z = dark green.

$-2V = 69^\circ - 73^\circ$ (measured on twenty-five grains).

ZAC = 18° (measured with reference to (110) cleavage trace).

$\gamma - \alpha = .017-.019$. $\gamma - \beta = .005$, $\beta - \alpha = .013$

Occasional grains of biotite are also seen. The accessory minerals include mostly ilmenite (around which biotite is developed) and magnetite.

Petrochemistry

A specimen from the fine-grained dolerite was analysed and its chemical analysis is set below alongside four others for comparison. Volumetrically, the analysed rock consists of plagioclase 44.2%, pyroxene 39.6%, hornblende 8.3% and biotite with accessories 7.9%. The C.I.P.W. Norm, Niggli values and basis are also calculated and given in Table II.

TABLE II

Constituents	I	II	III	IV	V
SiO ₂	.. 50.29	50.61	50.15	49.20	52.11
TiO ₂	.. 1.20	1.91	1.52	1.34	0.80
Al ₂ O ₃	.. 13.99	13.58	13.80	14.59	14.35
Fe ₂ O ₃	.. 2.87	3.19	3.76	3.50	1.38
FeO	.. 10.14	9.92	10.33	9.57	9.94
MnO	.. 0.34	0.16	0.26	0.40	0.18
MgO	.. 6.37	5.46	5.53	6.33	5.73

Constituents		I	II	III	IV	V
CaO	..	10.72	9.45	10.12	9.45	8.85
Na ₂ O	..	2.78	2.60	2.60	2.64	2.97
K ₂ O	..	0.60	0.72	0.57	0.63	1.15
P ₂ O ₅	..	0.02	0.39	0.18	0.17	0.24
H ₂ O+	..	0.31	1.70	0.83	2.08	2.08
H ₂ O—	..	0.25	0.43	0.37	0.39	0.17
Total	..	99.88	100.12	100.02	100.29	99.95
Sp. Gr.	..	3.08 at 30°C.	2.96	3.06	3.004	—

C. I. P. W. Norm

Q	..	—	4.32	2.52	0.60	0.12
Or	..	3.34	3.89	3.34	3.34	7.23
Ab	..	23.58	22.01	22.01	22.01	25.15
An	..	23.91	23.35	24.19	26.41	22.24
Di	..	24.31	17.44	20.69	17.84	17.32
Hy	..	14.83	17.88	17.28	20.94	21.78
Ol	..	2.83	—	—	—	—
Il	..	2.28	3.65	2.89	2.43	1.52
Mt	..	4.18	4.64	5.57	5.10	2.09
Ap	..	—	0.01	0.34	0.34	0.34
H ₂ O	..	0.31	2.13	1.20	2.47	2.25
	..	99.57	99.32	100.03	101.48	100.04

Niggli Values

Si	..	116.3	126.3	120.1	116.8	131.1
al	..	19.03	20.0	19.39	20.4	21.3
fm	..	47.23	47.3	47.84	48.6	45.6
C	..	26.66	25.3	25.86	24.1	23.8
alk	..	7.08	7.4	6.91	6.9	9.3
ti	..	2.08	3.6	2.73	2.4	1.5
p	..	—	0.42	0.14	0.14	0.15
K	..	0.118	0.15	0.125	0.12	0.23
mg	..	0.468	0.43	0.415	0.46	0.47

Constituents	I	II	III	IV	V
Niggli Basis					
Cp	.. —	0.12	0.03	0.03	0.03
Kp	.. 2.05	2.44	1.04	2.07	4.47
Ne	.. 15.38	14.64	14.59	14.57	16.52
Cal	.. 14.68	14.64	15.63	16.48	13.76
Cs	.. 9.08	7.49	7.81	6.41	6.70
Fs	.. 3.07	3.49	4.17	3.81	1.56
Fa	.. 11.95	12.27	12.68	12.09	12.10
Fo	.. 13.61	11.85	11.98	13.77	12.34
Ru	.. 0.85	1.40	1.10	0.92	0.57
Q	.. 29.33	31.66	30.97	29.85	31.95
Q	.. 29.33	31.66	30.97	29.85	31.95
L	.. 32.11	31.72	31.26	33.12	34.75
M	.. 38.56	36.62	37.77	37.03	33.30
γ	.. 0.241	0.213	0.213	0.178	0.178
π	.. 0.457	0.462	0.500	0.497	0.396
μ	.. 0.361	0.338	0.327	0.382	0.329
(f) Norm					
Ab'	.. 27.21	27.00	22.01	26.20	29.30
An'	.. 27.59	29.00	24.19	30.40	25.60
Di'	.. 28.06	22.00	20.69	19.20	20.40
Hy'	.. 17.14	22.00	17.28	24.20	24.70
(f) norm.	.. 122.75	122.00	122.54	120.30	126.90

I. R. 45. Fine-grained dolerite, Salem. Analyst. A. Dorairaj.

II. Average of eleven analyses of Deccan traps. Bull. geol. Soc. Amer. (1922). 33, 774. Analyst—H. S. Washington.

III. Middle portion of the dolerite dyke of Rifle Range, Pallavaram, (1954). J. Madras Univ. B. 24. pt. 1, 53-60. Analyst—N. Leelananda Rao.

IV. Average of eight analyses of Cuddapah traps (1946). Proc. Indian Acad. Sci. 23.A. 365. Analyst—N. A. Vemban.

V. Average of five analyses of Newer Dolerites of Bihar and Orissa. Three analyses, Rec. Geol. Surv. India (1932), 65, 528. Analyst—L. A. N. Iyer and two analyses, Rec. Geol. Surv. India (1936), 71, 108. Analyst—P. C. Roy.

From the mineralogical and chemical composition, it is seen that the analysed rock is close to a dolerite. It is also interesting to note that this dolerite closely resembles in composition that of Cuddapah trap and particularly the dolerite of Pallavaram, except for the fact that the dolerite of Salem is poorer in silica. The Newer Dolerites and the Deccan traps are richer in silica as seen from the Si ratio of the Niggli values. Mineralogically also, it is remarkable that the dolerite of Salem is free of pigeonite, and hypersthene of composition $En_{52}Fs_{48}$ occurs instead. Perhaps, a hypersthene of this composition showing lamellar structure possesses a reversion relationship with pigeonite (Hess 1941; Poldervaart, 1947). The Cuddapah traps are free from pigeonite (Vemban, 1946) while the Deccan traps and the dolerite of Pallavaram (Leelananda Rao, 1954) contain pigeonite. It is likely that the Salem dolerite is of the same age as the Cuddapah traps.

Since the (f) norm is very near to 123, plagioclase and pyroxene began to crystallise simultaneously and as the texture is very fine-grained, the depth of formation was possibly near the surface of the earth. The rock type belongs to Gabbroide Magmen, hawaitisch type of Niggli's magma types.

PART II

The Lamprophyre dyke

A dyke of lamprophyric character, a few yards wide, is noticed to run very near and parallel to the fine-grained dolerite dyke. The lamprophyre dyke is seen intruding into the pyroxenites of Chengaradu and continuing to the east of that hill towards Shervaroys, while the dolerite dyke continues into the Shervaroys through the western side of Chengaradu.

In a hand-specimen, the rock is dark-coloured, medium-grained and fresh-looking at the surface. Two specimens have been collected, one from the portion intruding into the pyroxenite in Chengaradu (R. 161) and the other, a mile and a half south west of this (R. 148). The rock has got a porphyritic texture, which is more evident in R. 161, containing phenocrysts of pyroxene embedded in a felsic matrix. The pyroxene plates exhibit a schillery lustre which is apparently due to the minute inclusions arranged in them.

In thin section, (Plate I, 2) it is found to consist of coarse-grained euhedral to subhedral plates of augite (4 mm. \times 2 mm. to

·1 mm. \times ·1 mm.) and subhedral to anhedral grains of olivine (3 mm. \times 1·8 mm. to ·14 mm. \times ·1 mm.) forming the phenocrysts, while the ground mass is composed of laths of orthoclase (2 mm. \times ·5 mm. to ·1 mm. \times ·06 mm.) and microcline (3·4 mm. \times 1·6 mm. to ·30 mm. \times ·20 mm.) with minor amounts of augite, olivine, biotite (1 mm. \times ·5 mm. to ·06 mm. \times ·06 mm.) ilmenite and magnetite. The felspar in R. 148 is fine-grained and studded with the same hair-like inclusions as found in the orthoclase of shonkinites. (Ramanathan, 1954). But, the orthoclase in R. 161 is comparatively coarse-grained and clear and free from inclusions. Biotite in R. 148 is found to develop around grains of ilmenite and also along the borders of pyroxenes while in R. 161, the biotite is seen to develop as a primary mineral.

Mineralogy

Felspars: The optical constants of the laths of felspar coincide with Nikitin's stereogram for orthoclase. The laths are found twinned according to complex carlsbad law. The optic plane is normal to (010). The optical data agree with the orthoclase described from the shonkinites from the same area (op. cit. 1954), except that no grain is found to be strictly uniaxial. The optic axial angle of the twinned grain varies from -26° to -42° (measured on twenty grains) and untwinned grains from -21° to -47° (measured on fourteen grains). Some of the twinned and untwinned grains, when their optical constants are plotted, coincide with Nikitin's stereogram for microcline and their optic axial angle varies from -50° to -70° (measured on five grains). In this low angle, they resemble microclines of high temperature (Köhler, 1948). The felspar grains are found to be intergrown submicroscopically with another mineral whose refractive index is higher than that of the felspar. From the higher refractive index and the normative mineral composition of the analysed specimen, this mineral is concluded to be nepheline. Following the data of Barth (1952, p. 97), as in the case of the shonkinite, the laths of felspar are named orthoclase. The orthoclase is at times exhibiting the murchisonite cleavage only and then it resembles the twinning in plagioclase. The felspar and nepheline are intergrown in random orientation. The felspar is found to be poikilitic with needles of melilite (?) and small grains of olivine, augite, iron-ore and biotite.

$$\gamma = 1.528-1.529. \quad \beta = 1.526-1.527. \quad \alpha = 1.522-1.523.$$

Augite: The mineral is colourless and occurs as euhedral to subhedral plates with distinct cleavages. There are a few grains twinned on (100). The augite is found to be studded with needles of an inclusion which are found to be arranged in definite crystallographic directions. In those cases where the inclusions are found to be arranged in only one direction, they are always parallel to the optic axial plane (010). In some cases, where there are two sets of inclusions, one set is parallel to (001) and the other to (100). In yet other cases, where there are three sets of inclusions, two are found to be parallel to (001) and (100) and the third irrational. The augite is lamellar at times and the lamellae are found to be parallel to (100). Sometimes, when the augite grain is twinned on (100), the inclusions parallel to (001) give a herring-bone appearance. The stereogram of such a grain is given in Fig. 1.

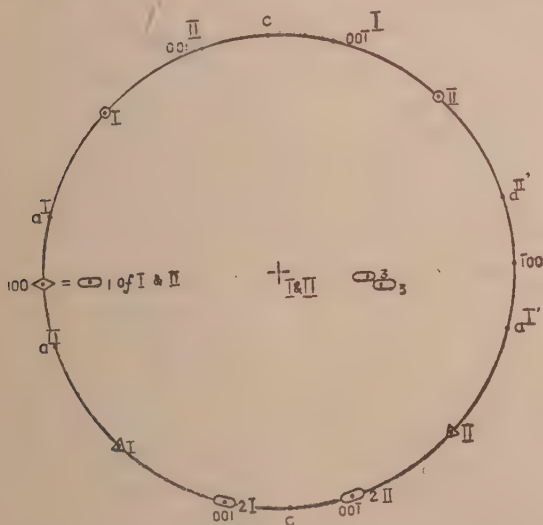


Fig. 1. Inclusions in a twin of augite in the lamprophyre dyke: Inclusions are arranged parallel to (001) and (100). The third direction of arrangement is irrational. I and II denote individuals of the twin, 1, 2 and 3 denote inclusions.

The augite is poikilitic with olivine and biotite and is often traversed by small veins of orthoclase intergrown with nepheline. The pyroxene is zoned and extinguishes in patches, but the different zones do not differ in their optic axial angle by more than 2° .

The augite is found to occur both as phenocrysts and in the groundmass, but the needles of inclusions and the optic axial angles are the same in both. The force of crystallisation of augite as suggested by the tendency towards euhedrism shows that pyroxene crystallised much earlier than the felspar. The mineral is named augite as a consequence of its optical data, though the optic axial angle is found to be unusually high.

The optical data are :

$+2V = 60^\circ - 66^\circ$ (measured on forty-four grains, the majority between $63^\circ - 65^\circ$).

$ZAC = 44^\circ - 46\frac{1}{2}^\circ$ (measured on five grains twinned on (100)).

$\gamma - \alpha = .025 - .029$. $\gamma - \beta = .016 - .020$. $\beta - \alpha = .006 - .009$.

Olivine : Olivine grains in this rock are subhedral to anhedral. Though they are zoned, they do not possess reaction-rims and are fresh. Only occasionally the mineral is altered along cracks. In R. 148, the olivine grains are crowded with ilmenite and iron-ore around which biotite is developed. In R. 161 the olivine is clearer and does not contain the inclusions. It is poikilitic with biotite and iron-ore. From the norm, the composition of olivine is calculated to be $Fe_{0.77}Fe_{2.23}$.

$+2V = 80^\circ - 82^\circ$ (measured on five grains).

$\beta = 1.675 - 1.679$. $\gamma - \alpha = .038 - .042$.

$\gamma - \beta = .020 - .022$. $\beta - \alpha = .018 - .020$.

Biotite : Biotite in R. 148 is found to be developed as a product of alteration from augite and as a reaction product around ilmenite grains and not as a primary mineral of crystallisation. But in R. 161, biotite is often found as a primary mineral of crystallisation. X = straw yellow. Y = Z = reddish brown.

Petrochemistry

To study the chemical relationship of the dyke-rock with the shonkinites from this area, R. 148, was chemically analysed and its chemical composition is set below along with others for comparison, in Table III. Volumetrically, the rock consists of orthoclase + nepheline + microcline = 34.6%, augite = 34.7%, olivine = 20.7%, magnetite and ilmenite with other accessories = 3.2% and biotite = 6.8%. The rock has got a specific gravity — 3.00 at 30°C.

TABLE III

Constituents		I	II	III	IV
SiO ₂	..	50.10	49.71	49.40	51.50
TiO ₂	..	0.41	1.40	1.10	1.85
Al ₂ O ₃	..	13.81	8.21	12.85	11.55
Fe ₂ O ₃	..	0.35	1.31	1.98	2.38
FeO	..	4.91	7.75	6.31	4.72
MnO	..	0.15	0.42	0.31	0.10
MgO	..	11.66	12.63	12.04	7.90
CaO	..	11.45	10.89	7.40	9.10
Na ₂ O	..	2.74	2.29	2.65	2.55
K ₂ O	..	3.99	4.34	1.35	5.65
P ₂ O ₅	..	—	—	0.24	0.96
H ₂ O+	..	0.22	0.38	3.10	1.10
H ₂ O—	..	0.10	0.11	0.20	0.45
		99.89	99.44	98.93+	99.81

+. Total does not include some minor constituents.

C. I. P. W. Norm

Q	..	—	—	—	—
Or	..	17.79	18.90	8.34	33.36
Ab	..	—	—	22.53	11.00
An	..	13.34	—	18.90	3.61
Lc	..	4.80	5.23	—	—
Ne	..	12.50	9.66	—	5.68
Ac	..	—	1.39	—	—
Di	..	34.81	43.53	13.53	28.34
Hy	..	—	—	13.64	—
Ol	..	15.09	16.31	13.28	7.10
Il	..	0.76	2.74	2.13	3.65
Mt	..	0.70	1.16	3.02	3.48
Ap	..	—	—	0.34	2.35
H ₂ O	..	0.22	0.38	3.10	1.10
		100.01	99.30	98.81	99.67

Constituents	I	II	III	IV
Niggli values				
Si	.. 105.10	103.0	111.9	127.8
al	.. 16.98	9.93	17.14	16.98
fm	.. 46.29	55.48	57.01	43.67
C	.. 25.79	24.26	17.96	24.30
alk	.. 10.94	10.33	7.89	15.05
ti	.. 0.629	2.24	1.90	3.57
K	.. 0.494	0.554	0.349	0.594
mg	.. 0.794	0.709	0.719	0.672
Niggli Basis				
cp	.. —	—	0.03	0.17
kp	.. 13.91	15.23	5.12	20.28
Ne	.. 14.23	11.26	14.69	13.86
Cal	.. 7.77	—	11.61	2.20
Ns	.. —	0.50	—	—
Cs	.. 12.68	16.16	5.46	12.68
Fs	.. 0.48	1.31	2.22	2.54
Fa	.. 5.50	9.43	7.85	5.58
Fo	.. 23.62	26.14	25.67	16.67
Ru	.. 0.27	0.99	0.80	1.35
Q	.. 21.54	18.98	26.53	24.45
Q	.. 21.54	18.98	26.53	24.45
L	.. 35.91	26.49	31.42	36.34
M	.. 42.55	54.53	42.05	39.21
γ	.. 0.300	0.305	0.133	0.339
π	.. 0.216	—	0.370	0.061
μ	.. 0.559	0.493	0.623	0.445

I. R. 148, lamprophyre dyke (olivine vogesite), Salem. Analyst, S. Ramanathan.

II. Average of two shonkinites, Salem. J. Madras Univ. B., 24. 1954. Analyst, S. Ramanathan.

III. Vogesite, Ards Peninsula, Co. Down. 1931. Geol. Mag. 68, 148. Analyst, D. L. Reynolds.

IV. Minette, ship rock, north-east Arizona, 1936. Bull. geol. Soc. Amer., p. 166. Analyst, H. Williams. (Quoted from D. L. Reynolds).

From the mineralogical composition, it is seen that the lamprophyre under discussion is very similar to the shonkinites already described. Chemically also it closely resembles the shonkinites, except that Al_2O_3 is more and FeO is less in the lamprophyre. It may be explained by the fact that anorthite appears in the norm, which might go to constitute the inclusions in augite. It is also seen that it chemically resembles the vogesite described by Reynolds. Mineralogically, however, the vogesite of Ards Peninsula contains both plagioclase and orthoclase feldspars, hornblende, quartz, chlorite and epidote. The minette of ship rock consists of orthoclase, diopside and biotite. Tyrrell (1948, p. 122) has classified the lamprophyre and calls it a vogesite when it consists of augite and/or hornblende, orthoclase being the predominant feldspar. The analysed rock contains augite, olivine, biotite, and orthoclase and microcline with nepheline. So, within the limits of petrographic nomenclature available, and commonly in vogue, the author calls this rock an olivine vogesite.

This is genetically related to the shonkinites as seen from its mineralogical and chemical composition and may represent its hypabyssal equivalent. The rock belongs to shonkinitische Magmen Shonkinitische type of Niggli's magma types.

PART III

Two dykes of doleritic character running parallel and very near to each other and extending N-S, from about a mile North of Sinduhalli to a little south of Dodkanya have been reported by Rama Rao (1926). They are exposed about half a mile west of Dodkanya, and specimens were collected from both the dykes. The more eastern of the two dykes is numbered D. 7, and the other D. 16. Mineralogically both are very similar and therefore only D. 16, which represents typically a dolerite, was analysed.

Besides these two a gabbroic dyke, running nearly N-S, over a distance of a mile and a half, a few furlongs to the west of Solerpura and Hebye (lat. $12^\circ 12'$ — $12^\circ 13'$ long. $76^\circ 41\frac{1}{2}'$ 57 D/12), beyond which it disappears inside the field, has been noticed by the author. Two specimens, one from near Hebye (D. 58) and another from near Solerpura (D. 67) were collected and both of them were chemically analysed.

SECTION A

Dolerite Dykes

The dolerite dyke rocks are dark-coloured, medium-grained and moderately fresh-looking at the surface. They contain phenocrysts of pyroxene and green olivine grains set in a ground mass of medium-grained felsic matrix.

In thin section, (Plate I, 3) they are found to consist of coarse-grained euhedral to subhedral plates of diopside (1.4 mm. \times 1.1 mm. to .14 mm. \times .08 mm.), titan-augite of the same size as diopside, and orthopyroxene (1.2 mm. \times 1.0 mm. to 0.1 mm. \times 0.1 mm.) besides subhedral to anhedral grains of olivine (1.4 mm. \times 1.4 mm. to 0.1 mm. \times 0.1 mm.) while the felsic material is laths of plagioclase (3 mm. \times 0.8 mm. to 0.06 mm. \times .06 mm.). There are euhedral plates of hypersthene often as big as 0.7 mm. \times 0.4 mm. The accessory minerals include biotite, magnetite and chlorite. The texture is distinctly ophitic, plates of pyroxenes enclosing a number of laths of plagioclase. D. 16, seems to be comparatively more altered. The plagioclase grains are smaller in grain-size. The pyroxenes are often altered to chlorite and epidote.

Mineralogy

Felspars: The plagioclase occurs as laths and plates of a grain-size nearly equal to that of the pyroxenes. Most of the plagioclase grains are twinned, and untwinned grains are also seen. The twin-laws determined on the plagioclase grains of both the dykes are given in Table I. The percentage of complex to simple law is as high as 80 and 60 in the two cases. The anorthite content also has got a wide range, from 45-70% in D. 7, and 40-70% in D.16. The plagioclase is often clouded with inclusions and is zoned, the different zones differing in their anorthite content by as much as 15-20%. They exhibit normal oscillatory zoning, the core being more calcic. The plagioclase grains have got a criss-cross arrangement and are poikilitic with olivine, biotite, chlorite and epidote. The normative proportion of albite and anorthite indicates the composition of the plagioclase as $Ab_{50} An_{50}$. The inclusions are found to be arranged mostly parallel to (010).

Pyroxenes: The orthopyroxene always possesses an euhedral outline and occurs as nearly square or stumpy prisms. It is found to be feebly pleochroic from pale green to light red. The clino-

pyroxenes which are subhedral and anhedral, include a titanaugite which is also feebly pleochroic, and diopside. The pyroxenes are poikilitic with olivine and plagioclase. They are altered along their edges to biotite, chlorite and epidote, while in D. 16 some pyroxene-grains are completely altered to chlorite and epidote. They have got a tendency to occur in glomeroporphyritic groups. In a number of cases, the pyroxene appears to be a single plate with continuous cleavages, without analyser, but under crossed nicols, there are a number of patches of pyroxenes, and in all cases, it is found to be an intergrowth of ortho- and clinopyroxenes (Stereogram, Fig. 2), such areas of intergrowth measuring 2 mm. \times 1.5 mm. It is seen that the two optic axial planes are at right angles to each other. The optic axial plane of augite intersects the obtuse angle of the cleavages, i.e., it is parallel to (010). The optic axial plane of hypersthene is at right angles to this and so its (100) coincides with (010) of augite. In other words (100) of augite coincides with (100) of hypersthene (after continental setting). This orientation has been discussed by Leelananda Rao (1954).

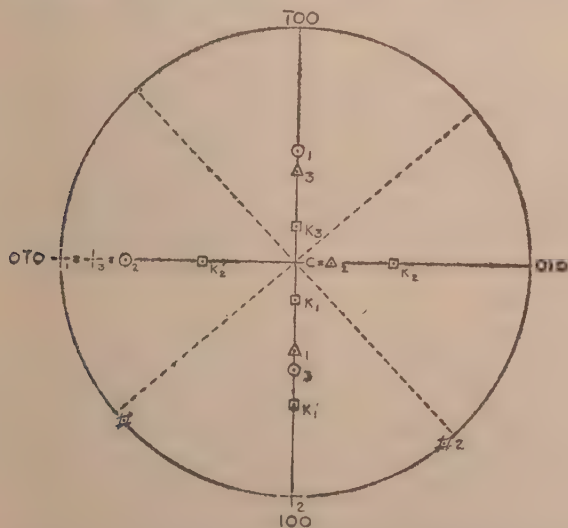


FIG. 2. Inter-growth of ortho- and clino-pyroxenes from the dolerite dyke, Dodkanya: (100) of augite coincides with (100) of Hypersthene (after continental setting)

The pyroxenes are granulated. A few grains of diopside and titan-augite are twinned on (100).

The optical characters are: —

Diopside: $+2V = 48^\circ - 54^\circ$ (measured on 42 grains)

$Z\Delta C = 39^\circ - 41^\circ$ (measured on three (100) twins)

$\gamma - \alpha = .030 - .032$, $\gamma - \beta = .023 - .025$, $\beta - \alpha = .007$

Zoned diopside:	Core	Rim
$+2V$	45°	47°

Titan-augite:

$+2V = 42^\circ - 47^\circ$ (measured on thirty grains)

$Z\Delta C = 44^\circ - 45^\circ$ (measured on five (100) twins)

$\beta = 1.683 - 1.684$.

$\gamma - \alpha = .023 - .025$, $\gamma - \beta = .017 - .018$, $\beta - \alpha = .004 - .006$.

Enstatite:

$-2V = 69^\circ - 75^\circ$ (Measured on 35 grains)

$\beta = 1.669 - 1.672$

$\gamma - \alpha = .011 - .013$, $\gamma - \beta = .005$, $\beta - \alpha = .006 - .008$

Zoned Enstatites:	Core	Rim
$-2V$	$.73^\circ$	69°
$\gamma - \alpha$	$.008$	$.013$

There are a few hypersthene grains, giving an angle of $-2V = 48^\circ - 49^\circ$, X = light red, Y = nearly colourless Z = light green;

The metasilicate molecules (clinopyroxene) when recalculated to 100, give the composition $Wo_{52} En_{32} Fs_{16}$ and the orthopyroxene has got a composition $En_{68} Fs_{32}$. These seem to be in fair agreement with the optical data given above (Muir, 1951; Poldervaart, 1947).

Olivine: The olivine grains are subhedral to anhedral and mostly possess double coronas and both the coronas are of bastite. Sometimes the olivine grains are completely altered to bastite so that only the outline of olivine is seen. The olivine is clouded with magnetite dust along cracks. The bastite is pale green in colour, fibrous, and has got a birefringence $\gamma - \alpha = .014$. The olivine has got a composition $Fo_{64} Fa_{36}$, as calculated from the norm. The optical data for olivine are:

$-2V = 79^\circ - 83^\circ$

$\beta = 1.718 - 1.720$.

$\gamma - \alpha = .040$, $\gamma - \beta = .018 - .019$, $\beta - \alpha = .021 - .022$.

Biotite: The biotite is found as a primary mineral but mostly altered to chlorite.

SECTION B

Gabbroic Dyke

The gabbroic dyke, in a hand specimen, is dark-coloured coarse-grained, and fairly fresh-looking at the surface. It consists of phenocrysts of pyroxenes and green grains of olivine in a matrix of plagioclase. The specimen from near Hebye (D. 67) is more coarse-grained and contains plates of pyroxene as phenocrysts.

In thin section, D. 58, (Plate I. 4) consists of plates of diopside ($1.4 \text{ mm.} \times .8 \text{ mm.}$ to $.05 \text{ mm.} \times .05 \text{ mm.}$) and enstatite ($1 \text{ mm.} \times .8 \text{ mm.}$ to $.1 \text{ mm.} \times .1 \text{ mm.}$) with olivine ($.6 \text{ mm.} \times .6 \text{ mm.}$ to $.06 \text{ mm.} \times .06 \text{ mm.}$) which occupy more than three-fourth of the volume. The felsic material is laths and plates of plagioclase ($1.4 \text{ mm.} \times .8 \text{ mm.}$ to $.06 \text{ mm.} \times .06 \text{ mm.}$). They are nearly equigranular and the ophitic texture of dolerites is indistinct. The texture is more towards the granulitic type than to ophitic.

In thin section, D. 67, (Plate I, 5) consists of large plates of plagioclase ($7 \text{ mm.} \times 2.5 \text{ mm.}$ to $.4 \text{ mm.} \times .4 \text{ mm.}$) clouded with inclusions and also coarse plates of subhedral diopside ($1.6 \text{ mm.} \times 1.0 \text{ mm.}$ to $1 \text{ mm.} \times 1 \text{ mm.}$) and orthopyroxene ($1.2 \text{ mm.} \times 1.0 \text{ mm.}$ to $.1 \text{ mm.} \times .1 \text{ mm.}$) with subhedral to anhedral grains of olivine ($1 \text{ mm.} \times .6 \text{ mm.}$ to $.1 \text{ mm.} \times .1 \text{ mm.}$). There are also euhedral grains of hypersthene ($.8 \text{ mm} \times .4 \text{ mm.}$).

Mineralogy

Felspars: In D. 58, the plagioclase grains are clouded and mostly twinned. They are both laths and grains. In the zoned individuals, the different zones show a variation in anorthite content to a maximum of 15 — 20%.

In D. 67, the plagioclase is more granular than lath-like and occurs as coarse-plates bigger than the pyroxenes. The plagioclase is much clouded and is pleochroic from X = dark brown to Z = light brown. The inclusions are found arranged mostly parallel to (001) while a subsidiary orientation parallel to (110) is also occasionally found. The plagioclase is not zoned as in the other case.

The twin-laws determined on both the rock types are presented in Table I. Most of the grains in D. 58 have got an anorthite content between 45 — 50% while in D. 67, they are more basic, about 60% An. This seem to agree well with the normative plagioclase, viz., D. 58. $\text{Ab}_{54} \text{An}_{46}$ and D. 67. $\text{Ab}_{31} \text{An}_{69}$. It is also interesting to note that even an occasional grain showing albite-albite twinning is noticed only in these two rocks among the five rock types under description, containing plagioclase.

Pyroxenes: Diopside and enstatite occur as subhedral to anhedral plates. The pyroxenes have got the same glomeroporphyritic grouping as in the case of the dolerite dykes. They constitute basic patches and occur in clots and are poikilitic with olivine. Some diopside grains are replaced wholly by hornblende or biotite. A few grains are also altered to chlorite and epidote:

The optical data are:

Diopside: $+2V = 45^\circ - 51^\circ$ (measured on more than 50 grains)

$\text{ZAC} = 39^\circ - 42\frac{1}{2}^\circ$ (measured on eight (100) twins)

$\beta = 1.710 - 1.712$, $\gamma - \alpha = .026 - .029$, $\gamma - \beta = .022 - .024$,
 $\beta - \alpha = .004 - .005$

Zoned diopside:

$+2V$	Core	Rim
	49°	46°
	47°	45°
	48°	45°

Enstatite: $-2V = 78^\circ - 87^\circ$ (measured on more than fifty grains)

$\beta = 1.700 - 1.703$

$\gamma - \alpha = .014 - .016$, $\gamma - \beta = .006 - .007$, $\beta - \alpha = .008 - .010$

Zoned Enstatites	Core	Rim
$-2V$	84°	79°
	85°	81°
	87°	84°

In D. 67., there are also a few hypersthene grains. They are found to occur near ilmenite grains and are pleochroic. X = reddish brown. Y = red. Z = green. Its optic axial angle varies from $-2V = 48^\circ - 51^\circ$.

The clinopyroxene molecules when recalculated to 100, give a composition $Wo_{52} En_{32} Fs_{16}$ in D. 58. and $Wo_{51} En_{30} Fs_{19}$ in D. 67, while the orthopyroxene has got a composition $En_{66} Fs_{34}$ in both the cases.

Olivine: Unlike in the other rock types, olivine in this dyke, has got a tendency to occur together in glomeroporphyritic groups and has got double coronas of bastite. The magnetite dust has got a definite orientation parallel to the C axis.

The optical data are:—

$$-2V = 84^\circ - 88^\circ \text{ (in D. 58 measured on 13 grains)}$$

$$-2V = 80^\circ - 82^\circ \text{ (in D. 67 measured on 8 grains)}$$

$$\beta = 1.719 - 1.722, \gamma - \alpha = .045 - .047, \gamma - \beta = .020,$$

$$\beta - \alpha = .025 - .027$$

Biotite is known to occur only as a product of alteration along with chlorite and epidote.

Petrochemistry

One of the dolerite dykes (D. 16) and both the specimens from the gabbroic dyke were chemically analysed and the results are set below along with a few others for comparison, in Table IV.

The modal compositions of the three rock types are as follows:
dolerite dyke: plagioclase 23.6%, pyroxene 51.0%, olivine 17.3%, and biotite with accessories 8.1%.

Medium grained gabbroic dyke, D. 58: plagioclase 25.4%, pyroxene 51.9%, olivine 16.8%, and biotite with accessories 5.9%.

Coarse-grained gabbroic dyke, D. 67: Plagioclase 42.8%, pyroxene 39.8%, olivine 7.4%, and biotite with accessories 10.0%.

TABLE IV

Constituents	A	B	C	D	E	F
SiO ₂	.. 50.08	51.36	49.29	53.82	53.05	46.37
TiO ₂	.. 0.53	0.35	0.24	0.33	1.77	0.79
Al ₂ O ₃	.. 6.74	8.43	12.98	8.07	8.91	16.82
Fe ₂ O ₃	.. 1.79	0.79	0.12	2.11	3.26	1.52
FeO	.. 11.84	9.98	8.40	7.00	9.52	10.44
MnO	.. 0.02	0.04	0.15	0.21	0.09	0.09
MgO	.. 15.81	13.02	9.82	18.39	14.42	9.61
CaO	.. 10.95	12.69	15.73	5.96	6.76	11.29
Na ₂ O	.. 1.34	1.85	1.52	1.28	0.66	2.45
K ₂ O	.. 0.54	0.30	0.32	0.82	0.48	0.20
P ₂ O ₅	.. 0.06	—	—	0.04	0.09	0.06
H ₂ O ⁺	.. 0.38	0.54	0.76	1.57	} 0.65	0.29
H ₂ O ⁻	.. 0.06	0.06	0.07	0.08		0.09
Total	.. 100.14	99.41	99.40	99.73	99.66	100.02
Sp. Gr.						
at 30°C.	.. 3.12	3.28	3.22	3.095	3.09	—

C. I. P. W. Norm

Q	.. —	—	—	1.08	8.94	—
Or	.. 2.78	1.67	1.67	5.00	2.78	1.11
Ab	.. 11.10	15.72	12.58	11.00	5.76	18.34
An	.. 11.12	13.62	27.80	13.62	19.74	34.19
Ne	.. —	—	—	—	—	1.42
Di	.. 34.60	40.05	40.96	12.82	10.44	17.25
Hy	.. 21.06	14.28	3.95	50.87	42.86	—
Ol	.. 15.31	11.56	11.55	—	—	23.36
Il	.. 0.91	0.76	0.46	0.61	3.50	1.52
Mt	.. 2.55	1.16	0.23	3.02	4.87	2.09

Constituents		A	B	C	D	E	F
Ap	..	0.34	—	—	—	0.34	0.34
H ₂ O	..	0.38	0.54	0.76	1.57	0.65	0.29
Total	..	100.15	99.36	99.96	99.59	99.88	99.91

Niggli Values

Si	..	95.99	104.8	102.7	112.3	116.9	95.19
al	..	7.58	10.03	15.86	9.9	11.6	20.32
fm	..	66.79	58.15	45.69	73.1	70.4	49.63
C	..	22.05	27.78	35.08	13.3	15.9	24.88
alk	..	2.98	4.04	3.37	3.7	2.1	5.17
ti	..	0.689	0.611	0.374	0.51	2.94	1.23
p	..	—	—	—	0.04	0.08	—
K	..	0.192	0.091	0.111	0.30	0.32	0.050
mg	..	0.680	0.686	0.672	0.78	0.67	0.595

Niggli Basis

Cp	..	—	—	—	—	—	—
Kp	..	1.66	1.00	1.01	2.98	1.69	0.67
Ne	..	6.99	10.04	8.10	6.95	3.73	13.31
Cal	..	6.65	8.20	16.86	8.11	12.03	20.48
Cs	..	13.09	14.89	15.24	4.80	4.24	6.55
Fs	..	1.84	0.84	0.22	2.15	3.56	1.50
Fa	..	13.64	11.65	9.89	8.28	11.30	12.10
Fo	..	32.84	27.27	20.74	38.08	30.57	19.97
Ru	..	0.33	0.28	0.17	0.22	1.30	0.55
Q	..	22.96	25.83	27.77	28.43	31.58	24.87
Q	..	22.96	25.83	27.77	28.43	31.58	24.87
L	..	15.30	19.24	25.97	18.04	17.45	34.46
M	..	61.74	54.93	46.26	53.53	50.97	40.67

Constituents		A	B	C	D	E	F
γ	..	0.213	0.273	0.331	0.090	0.085	0.163
π	..	0.435	0.426	0.649	0.449	0.689	0.594
μ	..	0.535	0.499	0.450	0.714	0.616	0.498
(f) Norm							
Ab'	..	14.25	18.79	14.75	12.46	7.31	26.28
An'	..	14.28	16.28	32.59	15.42	25.05	49.00
Di'	..	44.43	47.86	48.01	14.52	13.25	24.72
Hy'	..	27.04	17.07	4.65	57.60	54.39	—
(f) norm	..	165.30	153.77	121.46	173.98	158.91	75.72

A. Dolerite dyke. D. 16. Analyst, S. Ramanathan.

B. Olivine-gabbro dyke, medium-grained, near Solerpura, D. 58. Analyst, S. Ramanathan.

C. Olivine-gabbro dyke, coarse-grained, near Hebye, D. 67, Analyst, S. Ramanathan.

D. Coarse-norite, Durgapur (1936), M. S. Krishnan, Rec. geol. Surv. India, 71, 112. Analyst, P. C. Roy.

E. Augite-norite, Eriyur, South Arcot Dist. (1897) T. H. Holland, Rec. Geol. Surv. India. 30, Analyst, P. Brühl.

F. Noritic olivine gabbro, Wager, L. R. and Deer, W. A. Quoted from "Igneous and Metamorphic Petrology", by Turner and Verhoogen, (1951). P. 230. Analysis No. 2.

It is seen from the table that the dolerite dyke and the medium-grained portion of the olivine-gabbro dyke are nearly same in chemical composition and are similar to norite dykes, D and E, and therefore have noritic trends, while the coarse-grained portion of the olivine gabbro dyke has similarity to noritic olivine-gabbro.

All the three dyke rocks are genetically related. From the (f) norm, it is seen, that pyroxene crystallised far ahead of the plagioclase in D. 16 and D. 58, while plagioclase began to crystallise first and was immediately joined by pyroxene in D. 67. D. 67 may be taken as the source magma and the two dolerite dykes may represent the early squeezed out portion containing much pyroxene

in which plagioclase crystallised later in the intersertal spaces between the pyroxenes. This is also indicated by the modal proportions and textural relationships of the three dyke-rocks.

D. 16 is found to belong to Hornblenditische Magmen, diallagisch type (though it does not contain any hornblende), D. 58. to Pyroxenitisch Magmen, Pyroxenitisch type and D. 67 to Gabbroid Magmen, eukritisch type, of Niggli's magma types.

PART IV

Having considered the dyke rocks of the two areas in general, certain important conclusions can be arrived at about the dyke rocks of Salem and Dodkanya, which are listed below in tabular column, in Table V.

TABLE V

Dyke-rocks of Salem.

Dyke-rocks of Dodkanya, Mysore.

A. *Lamprophyre dyke.*

The dyke rock is related to Shonkinisch Magmen. Shonkintisch type. The lamprophyre dyke contains potash felspar of the type described from the shonkinites of this area.

No dyke of lamprophyric character.

B. *Dolerite dykes.*

1. The dolerite dyke belongs to Gabbroide Magmen, Hawaiisch type.

The three dyke-rocks belong to Hornblenditisch Magmen. Diallagisch, type, Pyroxenitisch Magmen, Pyroxenitisch type and Gabbroide Magmen, Eukritisch type.

2. The dolerite dyke has got a fine-grained texture and resembles a flow of basalt.

The dyke-rocks are coarse-grained.

3. The dolerite dyke does not possess ophitic texture.

The dolerite dykes are ophitic.

4. The plagioclase laths are invariably bigger than the pyroxenes which form the groundmass.

The pyroxenes are very coarse-grained.

5. The difference in anorthite content of the plagioclase is not very appreciable; only occasional grains are zoned.

The anorthite content differs by 15-20%; the plagioclase grains are often zoned.

6. The felspars are only occasionally clouded.

The felspars are invariably clouded.

7. Untwinned felspar grains are absent.

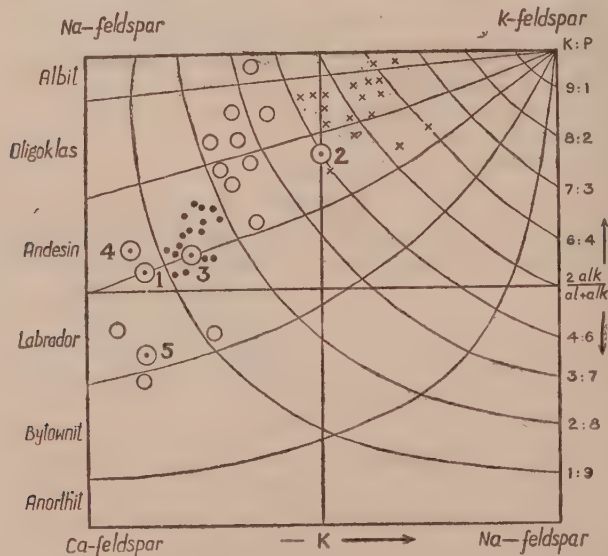
Untwinned felspar grains are common.

8. Pyroxenes are not zoned.

Pyroxenes are very often zoned.

9. Intergrowth between ortho- and clinopyroxenes are not seen. A single plate of pyroxene with continuous cleavages, appears under crossed nicols, as an intergrowth of two or more ortho- and clinopyroxene grains.
10. A little hypersthene is present. Both enstatite and hypersthene are present appreciably—16%–18%.
11. The dolerite is not olivine-bearing. The dolerite and gabbro dykes are olivine bearing.
12. The En : Fs ratio shows a higher amount of Fs than in Dodkanya. The En : Fs ratio shows a higher amount of En than in Salem.
13. The (f) norm indicates simultaneous crystallisation of pyroxenes and felspar. The (f) norm indicates a very much earlier separation of pyroxenes and the plagioclase joined only later.

The normative felspar molecules of the analysed rocks are calculated after the method of Niggli and their $K - \frac{2 \text{ alk}}{\text{al} + \text{alk}}$ values



- Laven des Lassen Peak Calif.
 ○ Laven Der Tristan da Cunha-Gruppe.
 × Lakkolithische intrusiva der Highwood Mts. Mont.
 1. R. 45. 2. R. 148. 3. D. 16. 4. D. 58. 5. D. 67.

Fig. 3. $K - \frac{2 \text{ alk}}{\text{al} + \text{alk}}$ diagram of Niggli: The felspar

of olivine-vogesite occupies a place among the rock types of the Highwood Mountains. The felspars of dolerites and the olivine-gabbro dyke take their positions near the rock types of Lassen Peak.

are plotted in Fig. 3. It is seen that the lamprophyre occupies a place near the rock types of the Highwood Mts. (Mediterranean Suite) while the dolerites and gabbro take their position near the rock types of Lassen Peak (Pacific Suite).

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The author places on record his deep sense of gratitude to Dr. P. R. J. Naidu for his constant help and guidance throughout the work.

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EXPLANATION TO PLATE

1. Plagioclase. 2. Orthoclase. 3. Augite. 4. Diopside. 5. Enstatite.
6. Hypersthene. 7. Olivine. 8. Biotite.

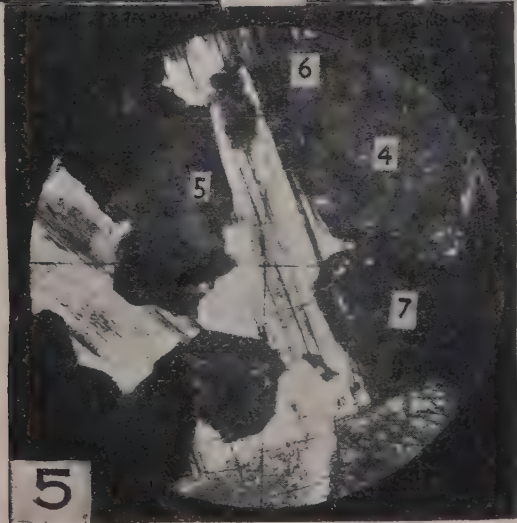
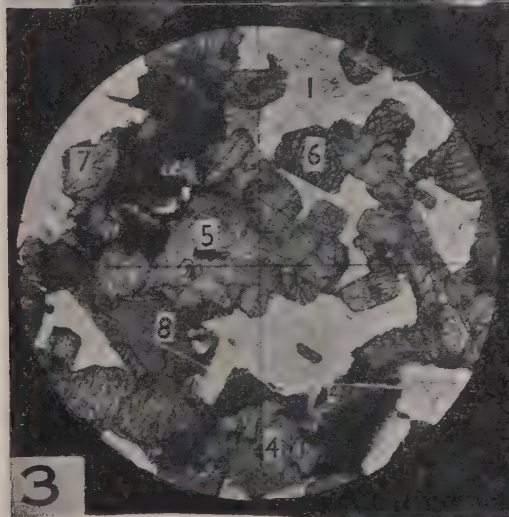
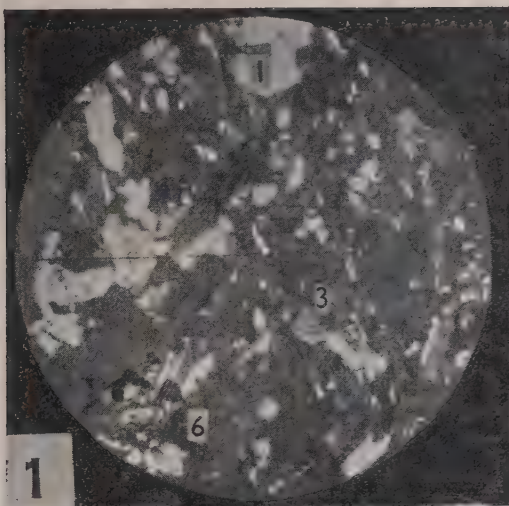
FIG. 1. Fine-grained dolerite from Salem with basaltic texture X Nicols. X 30.

FIG. 2. Vogesite from Salem. The orthoclase contains needle-like inclusions and the augite is studded with oriented inclusions without analyser. X 30.

FIG. 3. Olivine dolerite from Dodkanya indicating ophitic texture, plates of pyroxene enclosing laths of plagioclase. Hypersthene and diopside are often euhedral. Without analyser. X 30.

FIG. 4. Medium-grained portion of the olivine-gabbro dyke. The plagioclase is clouded and more lath-like than granular. The rock has got a sub-ophitic texture. Without analyser. X 30.

FIG. 5. Coarse-grained portion of the olivine-gabbro-dyke. The plagioclase is clouded and more granular than lath-like. The olivine has got double coronas. The texture is granulitic. X Nicols. X 30.



The Geology and Petrology of Pachaimalai

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ABSTRACT

Khondalitic suite of rocks are typically represented in Pachaimalai. Based on petrochemical studies it is concluded that the parent rocks of the Khondalite series are arkosic or micaceous sandstones partly very rich in quartz. Hedenbergite-garnet-magnetite rock occurring intimately associated with the khondalites shows close similarity to the related rock types of Eulysites of Loch Duich, Rossshire described by Tilley (1936). Charnockites and Enderbitic charnockites show intrusive relationship to the Khondalites. Field characters suggest that garnetiferous granulite (leptynite) is a reconstituted phase of khondalites. Dyke rocks show some interesting evidences of assimilation.

Introduction

Pachaimalai, (Lat $12^{\circ} 56'35''$ Long $80^{\circ} 7'38''$) situated to the west of the Tuberculosis Sanatorium between Chromepet and Tambaram, affords a very interesting study. Though it is in the proximity of Pallavaram, the type area of Charnockites of Sir Thomas Holland, it has not so far been studied in detail. The most prominent rock types not hitherto reported from this area are a group of Paragneisses belonging to the Khondalite series. Charnokites, Garnetiferous granulites (Leptynites), quartz-felspar veins and dyke rocks occur in close association with the khondalites and show interaction and reconstitution along contact zones and are thus of considerable geological and petrological interest.

Geology

The geological formations of Pachaimalai (Map. Fig. 6) may be classified as follows:—

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Dyke Rocks.

Garnetiferous Granulites and Quartz-felspar veins.

Charnockites.

Khondalite.	{	Garnetiferous quartzite.
		Garnetiferous biotite gneiss.
		Hedenbergite-garnet-magnetite rock.
		Garnetiferous sillimanite gneiss.

The paragneisses belonging to the Khondalite series outcrop dominantly along the northern and western portions of Pachaimalai and are undoubtedly the oldest formations. They are perfectly gneissose and bedded in character and the strike varies from N. 40° E.—S. 40° W to N.E.—S.W. The beds dip at 60° to 80° towards S.E. and in some parts, however, the beds are vertical. Some of the beds are highly jointed. The strike of the vertical joints swings from N.N.E.—S.S.W. to N.E.—S.W. and the horizontal joints dip at 20° to 30° towards S.E. The beds show lateral compositional variation in the direction of persistent strike and dip and the grain size becomes coarser as one proceeds from south to north. Garnetiferous biotite gneiss, Hedenbergite-Garnet-Magnetite rock and garnetiferous quartzite occur as intercalations in garnetiferous sillimanite gneiss.

The Charnockites occur as sills and dykes cutting through the khondalites either parallel to their strike direction or obliquely. The basic charnockites occur as bands in khondalites and garnetiferous granulite (Leptynite) and their strike varies from N. 30° E.—S. 30° W. to N.E.—S.W. On weathered surface they show a faint lineation. The intermediate and acid charnockites (Enderbite) occur in proximity to the basic charnockite which is adjacent to the khondalites. Enderbite shows a perfect foliation even on fresh surfaces due to the linear disposition of hypersthene. Acid charnockite occur to the east and west of Pachaimalai as distinct masses adjacent to garnetiferous granulites (Leptynites). They are highly jointed, the strike of the major and minor joints being N- 30° W—S. 30° E. and N. 30° E—S. 30° W respectively.

Garnetiferous granulites (Leptynites) are widely distributed along the eastern, western and central portions of Pachaimalai and occur very closely associated with the khondalites. They show faint banding approaching that of a migmatite. They grade often into the khondalites on the one hand and into less garnetiferous variety on the other. The strike varies from N. 20° E—S. 20° W to

N.40° E—S.40°W and dip at high angles towards S.E. like Khondalites. Patches of Khondalite occur as xenoliths in the granulites.

Quartz—Felspar veins cut across the khondalites and their contact is sharp.

Enstatite-Augite-Diorite dyke intrusive into the Khondalite is in some places 100' long and 30' wide. The strike swings from N.N.E.—S.S.W. to N—S. and is vertical and highly jointed. One set of joints strikes N.N.W.—S.S.E. and another set runs E—W. Due to assimilation of sillimanite gneiss it has given rise to a xenolithic micro-pegmatite in the contact zone.

Petrology of Khondalites

The important rock types comprising the khondalite series of Pachaimalai are the garnetiferous biotite gneiss, garnetiferous sillimanite gneiss, garnetiferous quartzite and hedenbergite-garnet-magnetite rock.

Garnetiferous Biotite Gneiss: It is a highly siliceous rock of banded appearance and of pale grey colour. A thin layer of biotite separates the bands of quartz and felspar with garnet.

In thin section it shows a typical gneissic texture (Plate 1, Fig. 1) and is comprised of quartz, perthite, microcline, biotite, garnet, and magnetite.

Quartz is present abundantly with its elongation parallel to the foliation and shows undulose extinction. Rutile occurs as minute needles, irregularly arranged in quartz. In some sections the average elongation ratio of quartz is as high as 3 : 1.

Microcline which is sparingly present shows its typical quadric structure. The optic axial angle varies from -78° to -83° and the extinction angle $\propto \wedge 001$ cleavage measured on grains perpendicular to γ gave an average value of $+10^\circ$.

Perthite is a fibrous variety of microcline micro-perthite and is anhedral. The fibrous appearance is due to the presence of minute spindles arranged parallel to Murchisonite cleavage (15. 0. 2.).

Biotite occurs as elongated flakes and sometimes shoots into quartz and perthite. The pleochroism is strong and the scheme is—

Z = Y, Dark Brown. X = Light Yellow.

TABLE 1

Constituents	Weight Percentage.	Granulite norm	Niggli Values	Mode
SiO ₂	82.25	Q — 67.32	Si — 637.70	
Al ₂ O ₃	8.98	Or — 10.01	al — 40.94	Quartz — 66.60
Fe ₂ O ₃	1.21	Ab — 5.24	fm — 42.80	
FeO	2.89	An — 1.95	c — 3.24	Perthite — 16.50
MnO	0.08	Cor — 5.41	alk — 13.02	
MgO	1.34	En — 2.70	ti — 0.93	Garnet — 6.50
CaO	0.42	Fs — 3.43	k — 0.64	
Na ₂ O	0.61	En — 0.80	mg — 0.38	Biotite — 8.70
K ₂ O	1.74	Fs — 0.79		
TiO ₂	0.16	Mt — 1.86		Magnetite — 1.70
P ₂ O ₅	Trace	Ru — 0.16		
H ₂ O+	0.24			
H ₂ O—	0.11			
Total	100.03			

Analyst : N. Leelananda Rao

Garnet of the almandine type is colourless and occurs as elongated crystals or as rounded grains with numerous inclusions of quartz and biotite.

The elongation of biotite, quartz and garnet which is so high in the crystalloblastic series reveals that the rock has been developed under sufficient shearing stress.

A fresh specimen was chemically analysed and is shown in Table I. As this rock contains the typomorphic minerals like quartz, felspar, almandine garnet and rutile of the granulite facies, the granulite norm as suggested by Eskola (1952) was calculated and is shown along with the Niggli values and mode in Table I.

The analysis shows that the necessary criteria for a sedimentary origin are satisfied. Potash and magnesia are in excess of soda and lime respectively. The presence of Corundum to the extent of 5.41% affords a partial confirmation.

The al, alk, c/fm values of Niggli when plotted in the appropriate triangle of Niggli fall in the field of "aluminous Sediments" (Fig. 1). This confirms the original sedimentary nature of the quartz biotite gneiss. The excess of quartz present in the rock also indicates that the original aluminous sediments should have been partly enriched in quartz.

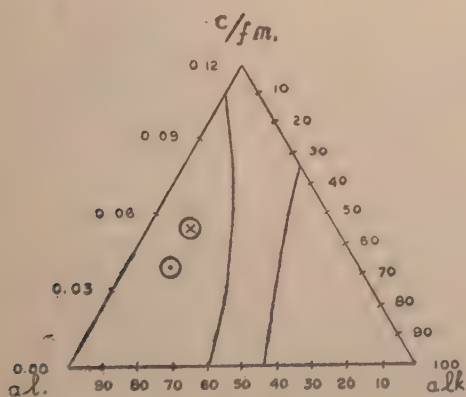
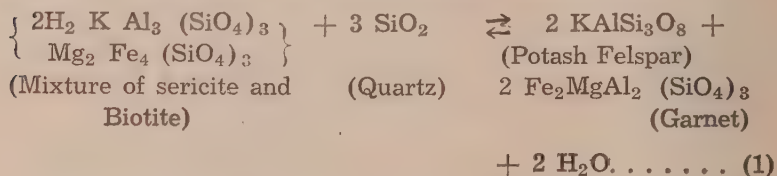


FIG. 1. al-alk-c/fm Diagram for the metamorphic rocks. (Johansen, 1939, p. 106)

⊙ = Sillimanite gneiss.

⊗ = Biotite gneiss.

The high grade metamorphism of argillaceous sediments has resulted in the formation of potash felspar from the more aluminous constituents like micas (sericite and biotite). The formation of potash felspar has set free an excess of alumina. In this rock, the excess of alumina has combined with the iron and magnesia constituents and has given rise to almandine garnet. The mineralogical changes involved in the production of potash felspar and garnet in this rock can be represented by the equation—



Garnetiferous Sillimanite Gneiss: The garnetiferous sillimanite gneisses can be grouped under two divisions as follows:

- (1) Garnetiferous biotite sillimanite gneiss
- (2) Garnetiferous sillimanite gneiss

Garnetiferous biotite sillimanite gneiss is a dark grey rock of banded appearance. The rose pink garnets show well-developed dodecahedral crystal outline and on weathered surfaces give rise to limonite.

In thin sections it shows an ill-developed and ill-defined gneissose texture (Plate I. Fig. 2.) and is composed of quartz, perthite, biotite, sillimanite, garnet and magnetite. Quartz occurs as anhedral grains of varying shape and size and shows undulose extinction. Rounded grains of Zircon and needles of apatite occur as inclusions in quartz. Microcline perthite is anhedral and fibrous. Microcline is sparingly present and shows wavy extinction. Biotite occurs as laths and shows pleochroism from light brown to yellow. Garnet is colourless and occurs as elongated grains. It is often diablastic with numerous inclusions of quartz, perthite, biotite, sillimanite and magnetite. The majority of the grains are isotropic but a few show anomalous birefringence. The average refractive index determined at 30° C on Leitz-Jelly Micro Refractometer is 1.919. The composition of garnet for this refractive index according to Fleischer (1937) is Grossularite 0.89%, Almandine 85.84%, Pyrope 8.76% and Spessartite 4.51%.

Sillimanite is an abundant constituent and is often found as slender prisms and plates and associated with perthite, biotite and garnet. The grain size varies from $0.80 \text{ mm} \times 0.16 \text{ mm}$. to $0.08 \text{ mm} \times 0.04 \text{ mm}$. (010) cleavage is perfectly developed in some of the grains. The optic axial angle varies from $+22^\circ$ to $+29^\circ$ in the plane parallel to (010). As there were number of (010) tablets α and γ were determined directly. $\alpha = 1.6560$; $\gamma = 1.6770$. The cross fracture parallel to (001) is seen in some grains. Sometimes it occurs as a rim around magnetite (Fig. 2).

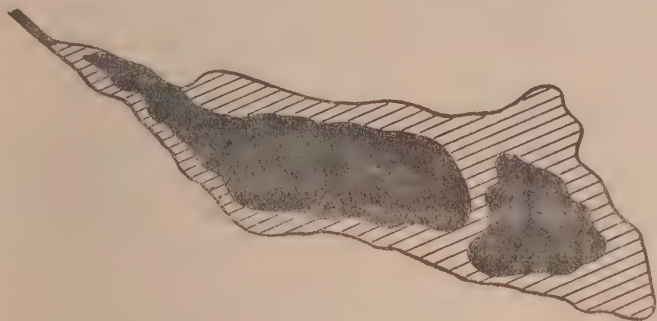




FIG. 2.

 = Magnetite.

 = Sillimanite.

Garnetiferous sillimanite gneiss is a white banded rock. The thin bands are greyish in colour and the width of the individual bands rarely exceeds $1/10$ of an inch. The pink garnets showing dodecahedral outline are present associated with quartz and felspar.

In thin sections it exhibits a perfect gneissose texture (Plate 1. Fig. 3) and is characterized by quartz, microcline, perthite, plagioclase, sillimanite, garnet, spinel and magnetite.

Quartz occurs as elongated grains and the elongation ratio of some of the grains exceeds 4 : 1. Liquid inclusions occur at right angles to the elongation direction. Some quartz grains occur bent around garnet.

Potash felspar is essentially microcline and is found as crushed grains in between the elongated plates of quartz. Some grains are drawn in the form of stringers. Fibrous perthite is present in very

subordinate amounts. The Plagioclase shows polysynthetic twinning lamellae and is twinned on the Albite law. It is oligoclase.

Garnet occurs as elongated plates parallel to the direction of gneissosity and are characterized by cracks parallel and perpendicular to the direction of elongation. Quartz, sillimanite, biotite and microcline occur as inclusions in garnet.

A deep green spinel belonging to hercynite-pleonaste group occurs associated with garnet and sillimanite and often forms an isotropic core to garnet (Fig. 3) and sillimanite (Fig. 4).

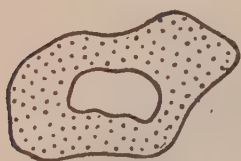




FIG. 3.



FIG. 4.

 = Garnet.

 = Sillimanite.

 = Magnetite.

 = Spinel.

A fresh specimen of garnetiferous biotite sillimanite gneiss was chemically analysed and is shown in Table II together with granulite norm, Niggli values and mode.

The chemical analysis reveals excess of Potash over Soda and magnesia over lime and these suggest the original sedimentary nature of the rock type. The al, alk, c/fm values when plotted in appropriate triangle of Niggli fall in the field of "aluminous sediments." (Fig. 1).

These characters indicate that the parent rock of garnetiferous sillimanite gneiss is arkosic or micaceous sandstone partly rich in quartz. The high grade metamorphism of the aluminous sediments has given rise to a rock which is characterized by quartz, biotite, perthite, microcline, oligoclase, sillimanite, garnet, spinel and magnetite. The formation of garnet and potash felspar in this rock can be

TABLE 2

Constituents	Weight Percentage.	Granulite norm	Niggli Values	Mode
SiO ₂	76.18	Q — 55.32	Si — 468.60	Quartz — 56.20
Al ₂ O ₃	14.83	Or — 12.79	al — 53.51	
Fe ₂ O ₃	1.21	Ab — 6.81	fm — 29.83	
FeO	2.76	An — 2.50	c — 3.33	Perthite — 20.30
MnO	0.03	Sil — 4.39	alk — 13.28	
MgO	1.02	Cor — 5.81	ti — 1.11	Garnet — 11.60
CaO	0.54	En — 2.60	k — 0.64	
Na ₂ O	0.78	Fs — 4.09	mg — 0.32	Biotite — 5.10
K ₂ O	2.21	Mt — 1.86		
TiO ₂	0.15	Ra — 0.15		Sillimanite — 5.20
P ₂ O ₅	Trace			
H ₂ O+	0.26			Magnetite — 1.60
H ₂ O—	0.10			
Total	100.07			

Analyst: N. Leelananda Rao

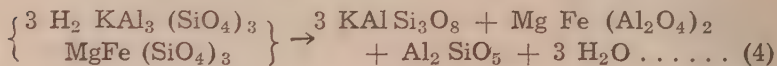
explained by equation (1). The association of garnet and spinel in some of these rocks can be represented by the equation,



The association of sillimanite with potash felspar as seen in thin sections indicates its derivation from sericite according to the equation,



The association of sillimanite with spinel in thin sections also suggests its formation from biotite according to the equation,



The association of magnetite and sillimanite also indicates that they are the degradation products of the biotite molecule.

The development of cracks in garnets parallel to the direction of gneissosity, the elongation of quartz and mylonitization of felspars suggest that these rocks were subjected to sufficient shearing stress.

Garnetiferous Quartzite: It is a fine to medium grained rock of reddish brown colour. It has a granulitic texture and consists mainly of quartz and garnet with minor amounts of perthite, biotite and magnetite.

Hedenbergite-garnet-magnetite rock: It is a massive coarse grained rock of high density and is recognised in the field by its characteristic limonitic weathering. Fresh fractured surface is dark in colour and has a resinous lustre. Pyroxene, magnetite and garnet occur intimately intermixed with each other (Plate 1. Fig. 4). Some specimens which are intruded by quartz veins show perfect banding.

In thin sections it is comprised of pyroxene, garnet, magnetite, quartz and apatite. The pyroxene is a green hedenbergite and shows pleochroism from pale green to dark green, the scheme being:

X = Pale green, Y = Yellowish green,
Z = Dark green.

TABLE 3

Constituents	Weight Percentage.	Granulite norm	Niggli Values	Mode
SiO ₂	43.72	Q — 14.80	si — 88.26	Quartz — 14.50
Al ₂ O ₃	2.50	An — 6.95	al — 3.03	
Fe ₂ O ₃	17.68	Wo — 16.82	fm — 75.51	Hedenbergite — 33.70
FeO	20.42	En — 5.30	c — 21.46	
MnO	0.92	Fs — 12.14	alk — —	
MgO	4.20	En — 5.2	tl — 0.36	Garnet — 25.20
CaO	9.85	Fs — 11.83	p — 0.24	Magnetite — 26.10
Na ₂ O	—	Mt — 25.75	c/fm — 0.23	
K ₂ O	—	Il — 0.46		Apatite — 0.50
TiO ₂	0.20	Ap — 0.67		
P ₂ O ₅	0.30			
H ₂ O ⁺	0.20			
H ₂ O [—]	0.15			
Total	100.14			

Analyst: N. Leelananda Rao

The optic axial angles measured between the emergences of two optic axes gave an average value of $+60^\circ$ in the plane parallel to (010). The extinction angle $Z \wedge C$ measured with reference to prismatic cleavages gave an average value of 48° . The refractive index β is 1.735. The birefringence determined with Berek Compensator computing the thickness with the adjacent grain of quartz is 0.026.

Garnet is pinkish in colour and it is an almandine variety.

Magnetite is an important constituent and occurs as irregular plates around the pyroxene. Quartz occurs interstitial to pyroxene, garnet and magnetite.

The chemical analysis of a fresh specimen is shown in Table III, together with the granulite norm, Niggli values and mode.

An inspection of the analysis shows that the rock is poor in alumina. The enrichment in lime, magnesia and iron suggests that ferrodolomite formed part of the original materials from which this rock is derived. The presence of high amount of iron also suggests that the parent material should be enriched in chalybite.

The paragneisses of Pachaimalai present a remarkable resemblance in their petrological characters to the paragneisses of Hutchinson area described by Tilley (1921).

THE PETROLOGY OF CHARNOKITES

Basic, intermediate, Enderbitic and acid charnockites occur closely associated with the Khondalites in Pachaimalai.

The basic charnockite is dark bluish grey in colour and is remarkably fresh. Under the microscope it shows a typical xenomorphic granular texture and is essentially made up of Plagioclase, Diopside, hypersthene, hornblende and magnetite.

Plagioclase occurs as twinned and untwinned laths and are free from clouding. The anorthite content varies from 55—40 per cent and the optic axial angle ranges from -88° to $+77^\circ$. The twin laws determined on 25 grains are shown in Table IV. Antiperthite occurs sparingly.

TABLE IV

Rocktype	Normal Law					Parallel Law					Complex Law		
	Number of grains determined	Albite	Manebach	Baveno right	Baveno left	Carlsbad	Acline = Manebach Ala	Periclinal	Ala	Albite-Ala	Albite-Carlsbad		
Basic charnockite ..	25	14	—	—	—	—	8	3	—	—	—		
Intermediate charnockite ..	12	8	—	—	—	—	2	2	—	—	—		
Enderbite ..	15	10	—	—	—	—	—	1	—	4	—		
Acid charnockite ..	15	9	—	—	—	—	—	—	—	6	—		
Garnetiferous Granulite ..	25	12	—	—	—	—	2	3	—	8	—		
Enstatite Augite Diorite .	50	10	3	1	1	9	2	3	—	6	15		

Diopside is greenish in colour in thin sections and shows parting perpendicular to the optic axial plane and parallel to (100). The optic axial angle is $+55^\circ$ in the plane parallel to (010). The extinction angle $Z \wedge C$ determined with reference to prismatic cleavages is 44° .

Hypersthene shows pleochroism from pink to green, the scheme being

$X = \text{Pink}, \quad Y = \text{Green}, \quad Z = \text{Colourless}.$

Parting parallel to optic axial plane and (100) is present. The optic axial angle is -55° in the plane parallel to (010) and $Z = C$. Hornblende occurs as an alteration product of hypersthene and magnetite and apatite are important accessories.

Intermediate charnockites besides containing the above said minerals is also characterised by antiperthite and quartz. The anorthite content of the plagioclase of the antiperthite varies from 35—45 per cent. The twin laws determined on 12 grains are shown in Table IV. The spindles of potash felspar in the plagioclase vary in their shape. The spindles are inclined to (001) cleavage at 72° on (010). In some grains there are two sets of spindles and they intersect at 71° on (010). The poles of the spindle axes lie near the emergence of C-axis.

Enderbite is a grey medium grained rock and shows a distinct foliation even on fresh surfaces due to the linear arrangement of hypersthene. Under the microscope it shows a xenomorphic granular texture (Plate 1, Fig. 5) and is essentially made up of quartz, antiperthite, plagioclase, hypersthene, magnetite and apatite. The antiperthite shows variation in anorthite content from 35—25 per cent and twin laws are shown in Table IV.

Acid charnockite is greyish in colour and shows a xenomorphic granular texture under the microscope. The essential minerals are quartz, microcline, microcline perthite, oligoclase, hypersthene, and magnetite. Biotite is an occasional accessory. Zircon and apatite are sparingly present. The twin laws of plagioclase are shown in Table IV.

The chemical analyses of basic, intermediate and Enderbitic charnockites are shown in Table V together with their C.I.P.W. Norm, Niggli values and mode.

TABLE V

Constituents		A.	B.	C
SiO ₂	..	50.26	64.82	75.17
Al ₂ O ₃	..	14.45	14.74	13.70
Fe ₂ O ₃	..	3.54	1.96	0.53
FeO	..	11.38	5.41	1.57
MnO	..	0.31	0.14	—
MgO	..	5.94	3.44	0.58
CaO	..	10.03	4.98	3.34
Na ₂ O	..	3.32	3.98	3.62
K ₂ O	..	0.45	0.83	0.92
TiO ₂	..	0.32	0.24	0.15
P ₂ O ₅	..	0.10	0.10	0.06
H ₂ O	..	0.06	0.12	0.40
Total	..	100.16	100.76	100.04

C. I. P. W. Norm

Q.	..	—	21.0	41.25
Or	..	2.78	5.0	5.56
Ab	..	27.77	34.06	30.39
An	..	23.35	19.46	15.85
C	..	—	—	0.89
Di	..	21.28	3.60	—
Hy	..	9.51	14.58	3.69
Ol	..	12.68	—	—
Mt	..	5.10	3.02	0.70
Il	..	0.61	0.46	0.30
Ap	..	0.34	0.34	0.34

Constituents		A.	B.	C.
Niggli Values				
si	..	117.70	218.60	411.40
al	..	19.95	29.15	44.00
fm	..	46.72	37.86	13.96
c	..	25.16	18.01	19.72
alk	..	8.17	14.98	22.32
ti	..	0.56	0.61	0.66
p	..	0.14	0.20	0.35
k	..	0.09	0.12	0.15
mg	..	0.45	0.46	0.34
Mode				
Quartz	..	—	20.4	42.0
Plagioclase	..	50.0	28.4	—
Antiperthite	..	3.2	29.5	53.2
Diopside	..	22.1	3.2	—
Hypersthene	..	18.5	15.0	3.5
Hornblende	..	0.5	—	—
Magnetite	..	5.4	3.2	1.0
Apatite	..	0.3	0.3	0.3

A.: Basic Charnockite, Pachaimalai. Analyst: N. Leelananda Rao.

B.: Intermediate Charnockite, Pachaimalai. Analyst: N. Leelananda Rao.

C.: Enderbite, Pachaimalai. Analyst: N. Leelananda Rao.

PETROLOGY OF GARNETIFEROUS GRANULITES

The garnetiferous granulites are medium to coarse grained, greyish-white rocks. Under the microscope they have a granulitic texture and are composed of quartz, microcline, perthite, antiperthite and oligoclase together with garnet, biotite and magnetite.

Quartz contains minute inclusions of rutile and shows crushing and granulation. Microcline and perthite are the abundant feldspars.

Perthites are mainly microcline micro-perthites. They occur as anhedral grains of the average size of 0.80 mm x 0.20 mm. Soda feldspar occurs as spindles of varying shapes in (010) sections and as blebs and irregular patches in (001) sections of microcline. The poles of the spindle axes appear near the emergence of C-axis on (001) plane of Nikitin's stereogram. In some cases the poles of the spindle axes are away from the emergence of C-axis, but usually lies in the a-c zone. Usually one set of spindles are present and they are either parallel to muchisonite cleavage (15.0.2.) or to albite twin plane (010). The spindles parallel to muchisonite cleavage make an angle of 71° with (001) cleavage on (010). Some grains show two sets of spindles and in such cases the spindles meet at an angle of 71° to 72° on (010) and at 90° on (100). When α of the microcline in the perthite is parallel to the axis of the microscope the spindles disappear and therefore it is concluded that α index of refraction of the host and the guest in the perthite is the same. But β and γ of the microcline are lower than the corresponding indices of the spindles. The birefringences of fairly large irregular patches of the guest determined by computing the thickness with adjacent grain of quartz are $(\gamma - \alpha) = .007$; $(\gamma - \beta) = 0.001$; $(\beta - \alpha) = 0.005$. These values indicate that the spindles are really potash feldspar rich in soda molecule and this is in accordance with the observation of Naidu (1954). As the spindles are grouped towards the centre of microcline and as they do not extend into the host from the margin they are considered to be exsolution products.

Antiperthite is sparingly present and the anorthite content of the plagioclase varies from 20% to 27% and the optic axial angle ranges from -74° to -82° . The twinning is on the albite law and the determination of twin laws of oligoclase is shown in Table IV.

Garnet is pinkish in colour and occurs as rounded and irregular grains. Biotite occurs as shreds and is formed due to alteration of garnet. Some of the granulites at the contact of khondalites contain needles of sillimanite.

A fresh specimen of the garnetiferous granulite was chemically analysed and is shown in Table VI along with granulite norm. Niggli values, and mode.

TABLE VI

Constituents	Weight Percentage.	Granulite Norm	Niggli Values	Mode
SiO ₂	72.95	Q = 36.77	si = 387.30	Quartz — 38.40
Al ₂ O ₃	14.20	Or = 21.68	al = 44.27	
Fe ₂ O ₃	1.10	Ab = 22.01	fm = 20.38	Perthite — 48.20
FeO	2.56	An = 8.34	c = 9.55	
MnO	0.06	Cor = 2.86	alk = 25.80	Oligoclase — 3.60
MgO	0.52	En = 0.90	ti = 0.64	
CaO	1.74	Fs = 2.51	k = 0.48	Antiperthite — 0.80
Na ₂ O	2.62	En = 0.40	mg = 0.20	
K ₂ O	3.73	Fs = 1.25		Garnet — 6.20
TiO ₂	0.15	Mt = 1.62		
P ₂ O ₅	Trace	Ru = 0.15		Biotite — 1.50
H ₂ O+	0.11			
H ₂ O—	0.28			Magnetite — 1.30
Total	100.02			

Analyst: N. Leelananda Rao

From the table it is evident that there is a slight discrepancy in the relative amounts of potash and soda feldspars of the mode and norm. This is due to the perthitic intergrowth of the entire alkali feldspar. The normative plagioclase corresponds to the oligoclase variety and is in agreement with the optical data. Garnet in the mode is represented by corundum, enstatite and ferrosillite molecules in the norm.

When the al, alk, c/fm values are plotted in the appropriate triangle of Niggli (Fig. 5) the point falls very close to the igneous field but still remains in the field of sediments. This points to the fact that garnetiferous granulites resulted due to granitization of khondalites. Further the presence of sillimanite in some of these granulites, the frequent occurrence of xenoliths of khondalites in the granulites and the gradational passage of the granulites into the khondalites suggest that the garnetiferous granulites (Leptynites) are merely a reconstituted phase of khondalites, with a certain amount of addition of granitic material from the acid charnockites and quartz feldspar veins which occur closely associated with the granulites, and this is in accordance with the observation of Krishnan (1947).

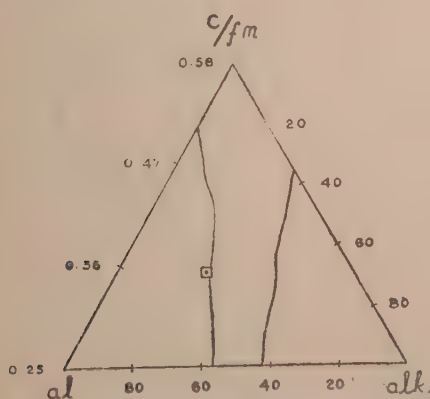


FIG. 5. al-alk-c/fm Diagram for the metamorphic rocks. (Johansen, 1939, p. 106)

◇ = Garnetiferous granulite (Leptynite)

PETROLOGY OF THE DYKE ROCKS

The dykes of Pachaimalai are mainly represented by Enstatite-Augite-Diorite Dyke. It is a tough black rock and exhibits under the microscope a subophitic texture (Plate 1, Fig. 6). Plagioclase is the most abundant feldspar and occurs as laths varying in size

from 2.4 mm. x 0.80 mm. to 0.4 mm. x .20 mm. Most of the grains show polysynthetic twinning lamellae and the results of determination of twin laws on 50 grains are shown in Table IV. Some plagioclase laths show zoning and the anorthite contents of these range from acid andesine ($Ab_{65} An_{35}$) at the margin to basic andesine ($Ab_{55} An_{45}$) in the intermediate zone and to labradorite ($Ab_{45} An_{55}$) at the core. The optic axial angle varies from -88° to $+77^\circ$, and the anorthite content of the laths ranges from $Ab_{65} An_{35}$ to $Ab_{47} An_{53}$. Almost all the laths of plagioclase show intense clouding which fades away along the margins.

Orthoclase, present sparingly in the micropegmatite portion is colourless and anhedral and shows variation in optic axial angle from -48° to -58° in the plane perpendicular to (010).

Enstatite is colourless and occurs as subhedral and anhedral plates with one set of cleavages. The actual optic axial angles observed in the plane (010) after applying Tröger's correction for an average β value of 1.7000 (the hemispheres used being of R.I. 1.648) are $+88^\circ$; $+86^\circ$; $+84^\circ$; -88° ; -82° ; -79° ; -78° and -76° . It shows straight extinction and $Z = C$. Refractive index gamma determined on cleavage flakes varied from 1.6770-1.6920. The average value of $\gamma = 1.6826$. The birefringences are $(\gamma - \alpha) = 0.0116$; $(\beta - \alpha) = 0.0064$. Therefore $\beta = 1.6774$. The optic axial angles and indices of refraction give on Hess's curves (1940) the composition range of enstatite as $En_{93} - of_7$ to $En_{80} - of_{20}$. From this it is evident that both enstatite and bronzite are present. Some enstatite plates show fine lamellae which behave like polysynthetic twins, twinned on a normal twin law. Following the crystallographic setting for orthopyroxene as adopted in the European continent, the lamellae were found to be parallel to (100). As these lamellae were too narrow it was not possible to determine the optical properties of the individuals. Hess (1940) explains these lamellae as due to exsolution.

Augite occurs as a rim around enstatite and as individual grains and plates. It is slightly pinkish in colour due to the presence of traces of titanium. A few grains are twinned on (100). The optic axial angle varies from $+40^\circ$ to $+56^\circ$ in the plane parallel to (010). Extinction ZAC determined with reference to prismatic cleavage is 44° . Refractive Index β determined on six grains gave an average value of 1.699. The birefringences determined are $(\gamma - \alpha) = 0.027$, $(\beta - \alpha) = 0.004$ $(\gamma - \beta) = 0.023$.

From Wager and Deer's curves the composition of Augite for $ZAC = 44^\circ$ and $2V = +48^\circ$ is 30 % of $CaSiO_3$, 42% of $MgSiO_3$, 28% of $FeSiO_3$. From Hess's $2V$ and β curves the composition is $Ca_{35.5} Mg_{38.5} Fe_{26}$. Some grains show herring-bone twinning and the twin plane between the two individuals is (100). The fine partings in the individuals are parallel to (001). The angular interval between the fine partings in the two individuals is 148° .

Pigeonite which occurs sparingly as patches in the augite plate is colourless in thin section. Prismatic cleavages at 88° are present in some of the patches. The actual optic axial angles after applying Tröger's correction are $+12^\circ$; $+18^\circ$; $+19\frac{1}{2}^\circ$; $+20^\circ$; $+20\frac{1}{2}^\circ$; $+25^\circ$ and $+30^\circ$ in the plane perpendicular to (010). Some are uniaxial. The optic axial planes of the grains which showed low optic axial angles below 20° were located by Turner's method (1940) of tracing the KY plane and locating Z polar to it. The average value of ZAC determined with reference to prismatic cleavages is 42° . The birefringences determined by computing the thickness with adjacent grains of quartz are $(\gamma - \alpha) = 0.027$, $(\gamma - \beta) = 0.026$. With these optical data the composition of pigeonite read on Hess's curves (1949) is 43% Fe atoms of total $Ca+Fe+Mg$ atoms and on Wager and Deer's curve (1937) is 13% $CaSiO_3$, 42% $MgSiO_3$, 45% $FeSiO_3$.

Augite borders are sometimes characterized by minute grains of hornblende which, perhaps, represents a preliminary stage in the process of amphibolization. Quartz occurring in the micropegmatitic portion exhibits myrmekitic intergrowth with plagioclase. Biotite is a secondary mineral and apatite is a minor accessory.

The chemical analysis of a fresh specimen is shown in Table VII together with C.I.P.W. norm, f norm and mode.

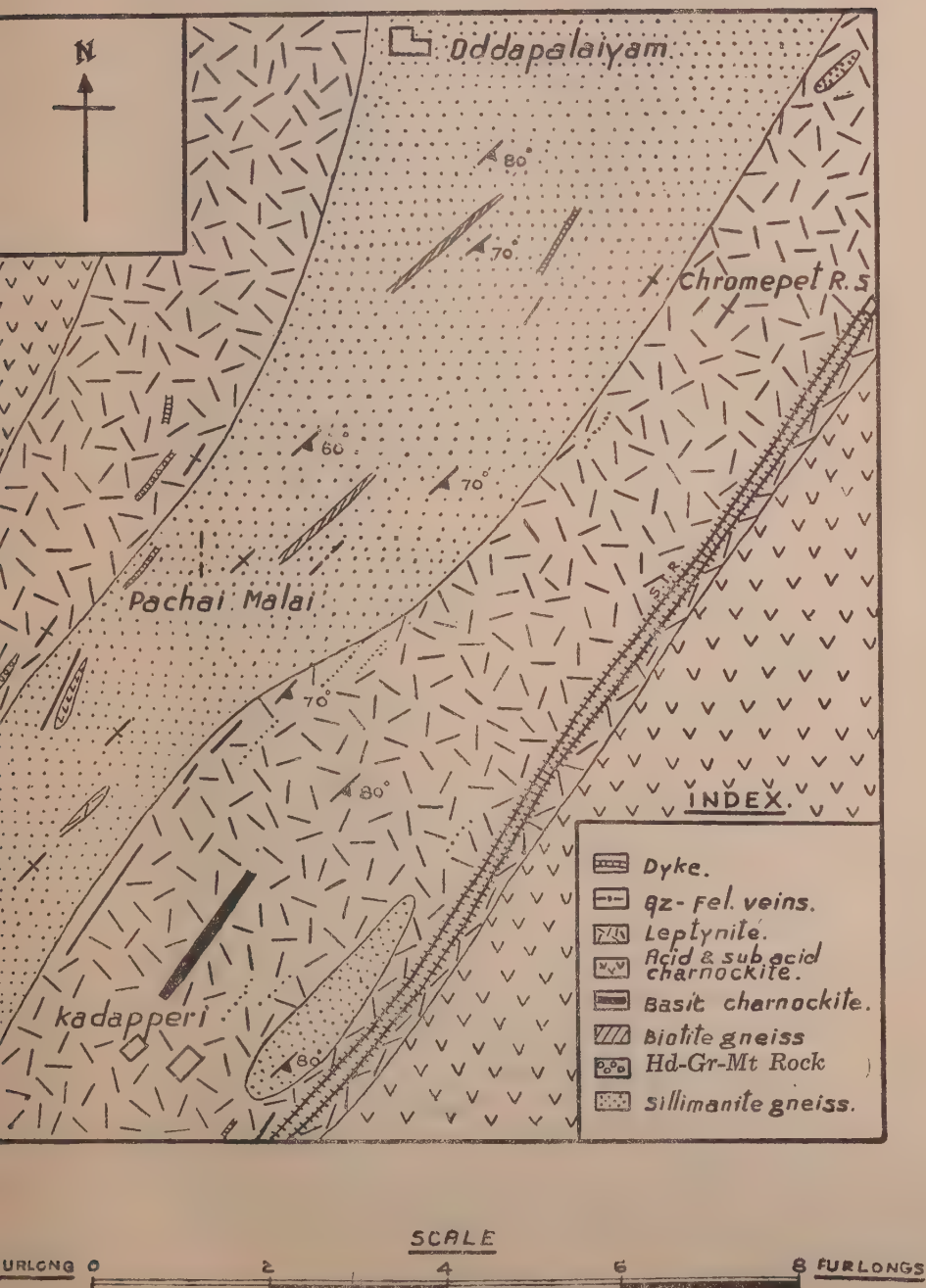
The normative composition shows 1.56 per cent of quartz and this occurs in the micropegmatitic portion of the enstatite augite diorite. The presence of orthoclase in the micropegmatite portion is reflected also in the norm. The anorthite content deduced from normative feldspars recalculated to a total of 100 closely matches with the optical data. The f norm calculated as suggested by Barth (1936) reveals that pyroxene crystallized first and that later both pyroxene and feldspar crystallized simultaneously. The micropegmatitic material is a primary product. Along the contact zone

TABLE VII

Constituents	Weight Percentage.	C. I. P. W. Norm	f-norm	Mode
SiO ₂	53.74	Q	—	1.56
Al ₂ O ₃	10.83	Or	—	8.90
Fe ₂ O ₃	3.34	Ab	—	20.44
FeO	9.92	An	—	14.18
MnO	0.06	Di { ^{Wo} En	—	10.44
MgO	9.57	Di { ^{Wo} En	—	6.20
CaO	7.92	Hy { ^{En} Fs	—	3.70
Na ₂ O	2.41	Hy { ^{En} Fs	—	17.70
K ₂ O	1.53	Il	—	10.69
TiO ₂	0.56	Mt	—	1.22
P ₂ O ₅	0.04		—	4.87
H ₂ O	0.11			
			ab'	— 24.52
			an'	— 17.01
			di'	— 24.40
			hy'	— 34.07
			Total f-norm	— 151.68
				Plagioclase — 29.8
				Micropegmatite — 15.6
				Enstatite — 25.6
				Augite — 20.7
				Hornblende — 0.3
				Biotite — 2.5
				Magnetite — 5.5
Total	100.03			

Analyst: N. Leelananda Rao

GEOLOGICAL MAP OF PACHAIMALAI.



with the sillimanite gneiss, the diorite has given rise to a xenolithic micropegmatite.

Xenolithic Micropegmatite: It is a bluish or bluish green rock in which basic material occurs as clots and patches. Under the microscope it exhibits a typical micropegmatitic texture (Plate 1, Fig. 7) due to the intimate intergrowth of quartz and microcline. The most abundant mineral is quartz and it occurs as big plates and anhedral grains. Needles and prisms of sillimanite are found as inclusions in quartz. The plagioclase feldspar shows clouding and it is andesine. Garnet and sillimanite occur as caught up patches in the plagioclase, and the garnet is associated with granules of hypersthene and flakes of biotite and magnetite. Myrmekite occurs at the contact of potash and soda feldspars. The basic patches (Plate 1, Fig. 8) are composed of plates of hypersthene which is intergrown with green spinel. Idiomorphic crystals of garnet and glomeroporphyritic groups of sillimanite occur in the hypersthene-spinel symplectite base. Hypersthene shows pleochroism, the scheme being,

X = Pink; Y = Yellowish brown; Z = pale green.

The optic axial angle measured directly between the emergences of two optic axes after applying Tröger's correction is -72° . (Enstatitic).

The chemical analysis of xenolithic micropegmatite is shown in Table VIII together with the C.I.P.W. norm and mode.

From the table it is evident that there is much discrepancy between the mode and norm. This is because of the intergrowth of the minerals giving rise to micropegmatite and symplectite. Chemical, optical and field data suggest that the xenolithic micropegmatite has resulted due to the assimilation of sillimanite gneiss by the enstatite-augite-diorite dyke.

The formation of garnet surrounded by a rim of plagioclase and associated with granules of magnetite, hypersthene, quartz and plagioclase can be explained by the equation,

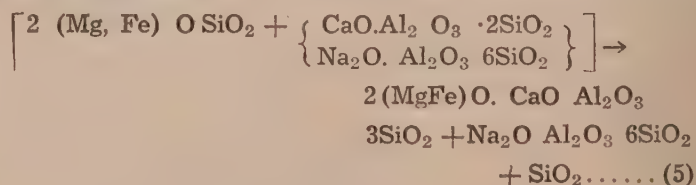


TABLE VIII

Constituents	Weight Percentage.	C. I. P. W. Norm		Mode
SiO ₂	78.20	Q	53.22	Quartz
Al ₂ O ₃	11.12	Or	22.24	Micropegmatite
Fe ₂ O ₃	0.80	Ab	9.96	Microcline
FeO	2.18	An	1.39	Plagioclase
MnO	0.03	Cor	4.59	Sillimanite
MgO	1.26	Hy } En Fs	3.20	Hypersthene
CaO	0.34		2.64	Spinel
Na ₂ O	1.16	Mt	1.16	Garnet
K ₂ O	3.76	Il	0.91	Biotite
TiO ₂	0.50			Magnetite
P ₂ O ₅	—			
H ₂ O+	0.33			
H ₂ O—	0.36			
Total	100.04			

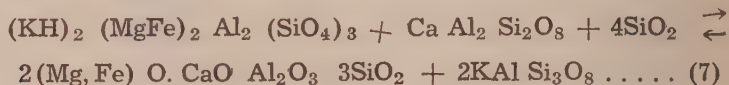
Analyst: N. Leelananda Rao

The occurrence of idiomorphic crystals of garnet in hypersthene-spinel symplectite base can be explained by the equation,



The association of garnet with potash felspar and the occurrence of biotite as a released mineral suggests its formation due to the reaction of hypersthene with microcline.

The formation of garnet associated with biotite, quartz and plagioclase can be explained by the equation,



The formation of spinel in this rock can be suggested by the equation,



The chemical, optical and field data confirms that the xenolithic pegmatite is a product of interaction between dioritic magma and sillimanite gneiss.

CONCLUSION

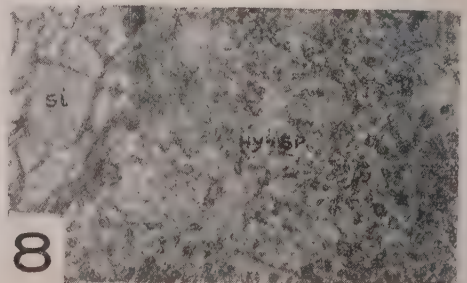
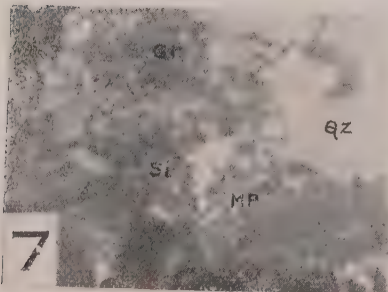
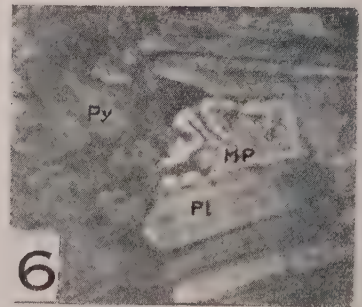
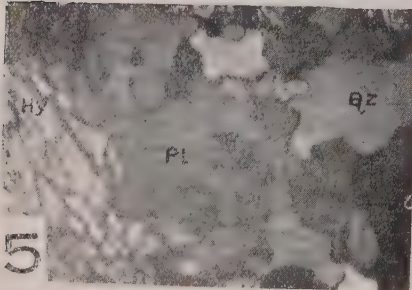
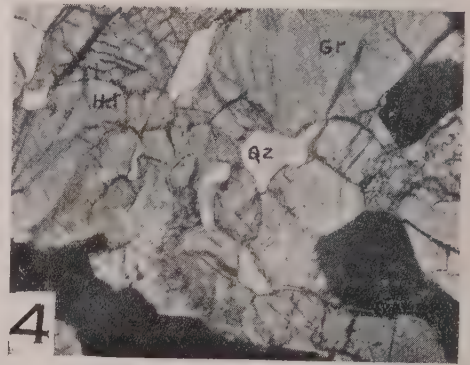
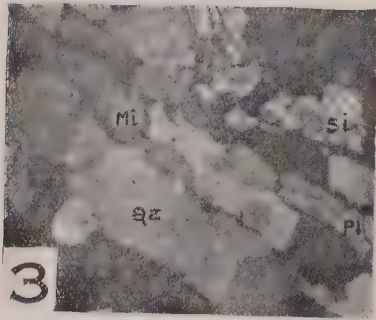
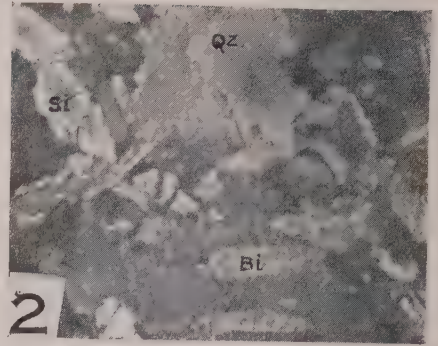
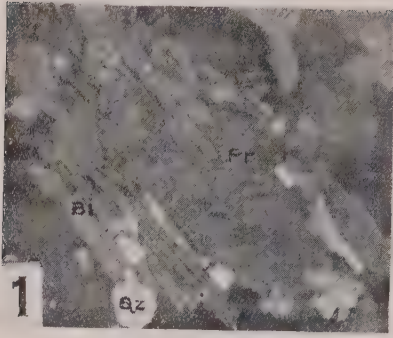
In Pachaimalai, we are dealing with varied metamorphosed sediments-aluminous to siliceous—with intercalated ferrodolomitic bands. These constitute the khondalite series. The khondalites have been intruded by charnockites, which show varying degrees of assimilation of the khondalites. The dykes of the area too show evidence of assimilation of the country rocks.

ACKNOWLEDGEMENT

I avail this opportunity of placing on record my deep indebtedness to Dr. P. R. J. Naidu for his suggestions and guidance.

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EXPLANATION TO PLATE

FIG. 1. Microphoto of biotite gneiss showing a gneissic texture. Flakes of biotite (Bi) is present paralld to gneissosity and associated with perthite (Pr) and quartz (Qz) X Nicols. X 32.

FIG. 2. Microphoto of biotite sillimanite gneiss showing quartz (Qz), biotite (Bi) and sillimanite (Si) X Nicols. X 32.

FIG. 3. Microphoto of sillimanite gneiss showing elongation of quartz (Qz) and sillimanite (Si). Microcline (Mi) and plagioclase (Pl) occur as crushed grains X Nicols. X 32.

FIG. 4. Microphoto of Hd-Gr, Mt rock showing hedenbergite (Hd), garnet (Gr), magnetite and quartz (Qz). X 32.

FIG. 5. Microphoto of Enderbite showing plagioclase (Pl), Hypersthene (Hy) and quartz (Qz). X Nicols. X 32.

FIG. 6. Microphoto of Enstatite-Augite-Diorite showing pyroxene (Py), plagioclase (Pl) and micropegmatite (Mp). X Nicols. 32.

FIG. 7. Microphoto of Xenolithic pegmatite showing micropegmatite (Mp), plagioclase, quartz (Qz) and sillimanite (Si). X Nicols. X 32.

FIG. 8. Microphoto of Xenolithic pegmatite showing a bunch of sillimanite (Si) in a hypersthene-spinel symplectite base. X 32.

On the Charnockites of Pallavaram

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ABSTRACT

The field relations between the metamorphic granulites and the acid charnockites are described. The petrographic characters of the transitional rocks between the granulites and the acid charnockites are also presented. It is suggested that the acid charnockites are formed by migmatization (under granulite facies conditions) of the granulites, mainly the "norites".

The results of the microfabric studies of a few types are also included. So far such work has not been attempted for the charnockites from the type area. The initial results indicate that the charnockites and associated rocks are B-tectonites, and that the suggested migmatization (and the metamorphism) of the granulites is syntectonic.

INTRODUCTION

Holland (1900) described in his classic memoir, the field and petrographic characters of the various rock types that occur in the St. Thomas Mount-Pallavaram area near Madras, South India, and he grouped all the hypersthene bearing rocks of the area in a series—the 'Charnockite Series.' Holland has mapped continuous bands of acid charnockite and norite, and in certain areas, a mixed rock composed of alternating bands of norite and acid charnockite (Holland, 1900, pp. 137, 172). He has also reported the occurrence of garnetiferous leptynites developed at the contacts of norite and acid charnockite (op. cit., pp. 142-143).

Rajagopalan (1946, 1947) has, on the basis of chemical study of the various rock types of the area, concluded that the basic, intermediate and the acid charnockites form an igneous differentiation series.

Muthuswami (1951) has described the occurrence of garnet-diopside granulite and scapolite-calc granulite in the area.

In a later publication (1953) he has discussed the status of all these rocks in the facies system.

The large number of quarries that have been opened in the area in recent years have brought to light excellent exposures. These show certain intimate relationships between the various rock types, which are described in the present paper. The area studied is between Long. $80^{\circ} 5'E$ — $80^{\circ} 12'E$ and Lat. $12^{\circ} 55'N$ — $13^{\circ} 0'N$, and is situated to the south of Madras. As the previous workers have not published a map of the area, the area has been mapped geologically in the course of the present work, and a fact map is presented with this paper.

In view of the fact that no published work exists on the micro-fabric of the charnockites and associated rocks of the area, an attempt has been made in this direction. It must, however, be stated that, the work so far done can only be considered as very limited in character. Unless a larger number of samples are analyzed, no large scale generalisations regarding the structural history of the complex are possible.

The nomenclature of the rock types as used by Holland is retained in this paper to avoid ambiguity. *No genetic significance is to be attached to such terms as norite, etc.*

Rock Types

The three major rock types that can be recognized in the area are the norites, leptynites and the acid charnockites.

Locally, certain variations of the norites have been observed. A garnetiferous variety, composed in the main of lime rich minerals like diopside, calcic plagioclase, sphene, and lacking in hypersthene, with small, elongated lenses of scapolite-calc granulite is present (Muthuswami, 1951). The lenses of scapolite-calc granulite are elongated parallel to the foliation in the garnet-diopside granulites and the adjacent norite and leptynite. Another variety, garnet-hornblende-spinel rock (Muthuswami, 1953) occurs sporadically as small lenses in the norite.

Sillimanite-quartz-garnet granulite* occurs as a half-mile long band west of Mile 17 on the Railway. The rock marginally grades into leptynite.

* Our attention to the occurrence of this rock type in the area was first drawn by Dr. A. P. Subramaniam of the Geological Survey of India.

PLATE I



FIG. 1. Thin, impersistent, bluish quartzofeldspathic veins in norite. Note the parallelism of the veins to each other.

FIG. 2. Lenses of norite in acid charnockite; note the thin acid charnockite vein in norite.

FIG. 3. Parallel, biotite-enriched lenses of norite in acid charnockite.

The norites, garnet-diopside granulites (with intercalated lenses of scapolite-calc granulite), the leptynites and the garnet-sillimanite-quartz granulites occur as bands and lenses of varying sizes in an acid charnockitic country.

Small lenses of leptynite have been observed in the norites and *vice versa*. There is a quick gradation at the boundaries between these rocks.

The general strike of foliation of all the rock types is, in the region west of Pallavaram, NNE-SSW. To the east, however, the strike varies from ENE-WSW to E-W. The lineation is, in all cases, in the plane of foliation and is sub-horizontal. The strike of foliation of, and the lineation in, all the rocks are parallel to each other. No discordant contact has been observed in the area.

The relationship of the acid charnockites with the other rocks like the norites, leptynites and the other granulites are described in greater detail in the following pages.

Norites and acid Charnockite

Norites occur as rather uniform bands and lenses of varying dimensions in the acid charnockites. The largest of such bands is nearly two hundred yards across and about half a mile in length, and outcrops NE of Tirunirmalai. Normally however, the bands are of much smaller size. Quartzofeldspathic veins of all sizes are seen within the norites, and these veins are all elongated parallel to the foliation in, and the general trend of, the norite bands. Similar observations have been made by Holland (op. cit., p. 137). Marginally, the norites grade into a *mixed rock* formed of alternating bands of norite and acid charnockite. This heterogeneous rock has been termed 'intermediate charnockite' by Holland (op. cit., p. 147). Indeed several of the noritic outcrops, on closer examination are seen to consist of such alternating bands. The noritic bands, in these zones, are seen to be greatly enriched in biotite, an otherwise rare constituent in the normal norites and acid charnockites. There is every gradation between a rock mainly composed of norite with thin, impersistent, parallel veins of quartzofeldspathic material (Plate I, fig. 1) to a highly quartzose rock with stray stringers, narrow lenses and streaks of norite (Plate I, fig. 2). This gradation is seen to occur both along and across the strike, and all the bands, stringers and lenses, whether of acid charnockite in norite, or of norite in acid charnockite, are found to show a re-

markable degree of parallelism to each other and to the strike of foliation of the adjacent rocks (Plate I, fig. 3). The noritic bands, stringers and lenses grade imperceptibly into the acid charnockite (Plate I, fig. 2). By an increase in the number and thickness of such acid charnockite bands, and by a gradual disappearance of the noritic ones, the rock grades into uniform acid charnockite.

Coarse-grained segregations of pyroxene have given rise to elongated lenses of pyroxenite in the norite. Such 'schleiren' have their long axes parallel to the foliation in the norite.

Thin sections of the norite in various stages of its transition to acid charnockite have been examined. Hypersthene, diopside (with some intergrown pyroxenes of the Bushveld type) and plagioclase, with in some cases garnet, form the mineral assemblage of the norites which are not veined by acid charnockite (Table I, mode A). The texture is typically xenomorphic granular.

Nearer the margins of the larger bands of norite, the norite is increasingly veined by acid charnockitic material. The quartzofeldspathic veins are coarse-grained, and are composed in the main of plagioclase and quartz with sparsely distributed pyroxenes. In the basic bands, there is a significant increase in the quartz content (Table I, mode B), the quartz clearly replacing the plagioclase (Plate II, fig. 3). Hornblende, which was present in the unveined norite, is absent in these rocks. There is, however, an increase in the amounts of ore and total pyroxenes (Table I, mode B). This point is interesting in the light of Ramberg's views on the stability of hornblende in the granulite facies (1952).

In those zones where the norite is highly veined or banded by acid charnockite, the norites occur as thin, concordant bands, lenses or streaks in coarse grained acid charnockite. The noritic bands and lenses are here greatly enriched in biotite. The biotite shows radial growth and sieve texture, and in certain cases replaces pyroxenes and grows into plagioclase and quartz. In the basic bands, quartz is present in increasing amounts as compared with the less veined norites (see Table I, mode C), and occurs as irregular patches, veins in and myrmekitic intergrowths with plagioclase. Quartz clearly replaces plagioclase. Sphene is present in small quantities.

In the acid bands, quartz occurs as large, lenticular plates surrounded by a mosaic of finer grained quartz and plagioclase. Potash

PLATE II.

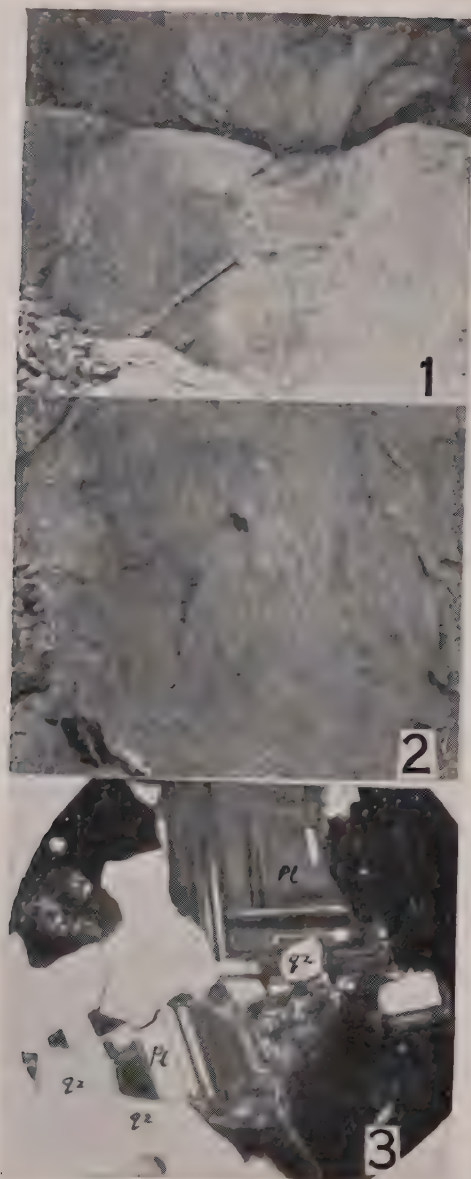


FIG. 1. Leptynite grading along the strike into acid charnockite. Note the continuation of trains of minerals from leptynite into charnockite (near head of hammer).

FIG. 2. "Ghost" leptynitic patch in acid charnockite (light coloured portion in the middle of picture). To the left can be seen a band of leptynite.

FIG. 3. Quartz (qz.) replacing plagioclase (pl). Note the small blebs of quartz in the plagioclase. Norite veined by acid charnockite.

feldspar, an ordinary constituent of acid charnockites is absent in the mixed rocks composed of norite and acid charnockite. Holland (op. cit., p. 147) states that orthoclase is a common mineral in the intermediate charnockites. In the mixed rocks described, all the grains of doubtful identity between quartz, untwinned plagioclase and orthoclase were checked on the universal stage; it was found that most of them were quartz, and the rest showed the twinning lamellae of plagioclase on high inclination of the stage. No orthoclase was observed.

The acid veins are generally coarse-grained and contain only occasional dark minerals (Table I, mode D).

TABLE I

	A	B	C	D
Hypersthene	27.79	19.87	14.96	0.39
Diopside	6.14	19.16	20.14	0.55
Hornblende	16.43	—	—	—
Biotite	—	—	14.33	0.41
Plagioclase	45.63	45.04	36.59	46.97
Quartz	1.08	9.79	13.64	51.70
Magnetite	2.96	6.07	0.39	—

A. Unaltered norite, from hill north-east of Tirunirmalai.

B. Slightly migmatized norite, from hill north-east of Tirunirmalai.

C. Norite band in highly migmatized norite, Cheri Hill.

D. Acid vein, highly migmatized norite, Cheri Hill.

Quartz, plagioclase and small amounts of pyroxenes constitute the mineral assemblage of the acid charnockites veining the norites. The coarse grain of the rock prevents reliable modal analysis.

Leptynite and acid Charnockite

Wherever leptynite and acid charnockite occur together, the leptynites are found as lenses in the acid charnockite, and, there is an intimate intermixture of the rocks, one gradually passing into the other, without any sharply definable junction (Plate II, Fig. 1). Holland (op. cit., p. 174) has also observed such gradational con-

tacts. The acid charnockite in such cases is garnetiferous. 'Ghost' patches of leptynite occur frequently in acid charnockite, and the foliation in such patches parallel that in the acid charnockite and the larger bands of leptynites (Plate II, fig. 2). The undisturbed continuation of trains of minerals, particularly garnet, from the leptynite into acid charnockite is noteworthy. Bluish, quartzofeldspathic veins of all sizes occur in the leptynites paralleling the foliation in them and the length of the leptynite bands; even larger concordant lenses of acid charnockite up to ten feet in length have been observed in the leptynites.

Quartz, garnet and plagioclase form the mineral assemblage of the leptynites and a granulitic texture is characteristic. Specimens collected at regular intervals from the leptynite to the acid charnockite showed that microclinisation of both quartz and plagioclase characterise the mineralogical changes in the transitional varieties. The results of the modal analyses of samples collected in such a traverse show the steady increase in potash feldspar content and the reduction in the amounts of plagioclase as the acid charnockite is approached (Table II).

TABLE II

		E	F	G	H	I	J
Garnet	..	11.51	4.81	2.82	9.16	11.61	9.50
Plagioclase	..	28.28	21.74	38.32	28.61	8.68	16.64
Microcline	..	2.40	8.35	7.83	4.77	11.74	14.31
Quartz	..	56.80	64.97	49.79	55.09	66.95	58.42
Magnetite	..	1.03	0.06	0.78	1.45	1.00	0.44
Biotite	..	—	—	0.69	0.93	—	0.70

E. Leptynite, Cheri Hill.

F, G, H, I. Specimens of the intermediate, transitional varieties to acid charnockites, Cheri Hill.

J. Acid charnockite, Cheri Hill.

Biotite, an important constituent of the migmatitic norites, is absent in these zones. The larger grains of bluish quartz in the acid charnockite in the vicinity of leptynites have presumably been formed by a recrystallisation of the sugary quartz in the leptynites.



PETROFABRIC DIAGRAMS

Other Rock Types

The garnet-diopside granulites (with associated lenses of scapolite-calc granulites) have also been veined by bluish quartzofeldspathic material to a limited extent.

Marginally, the garnet-sillimanite-quartz granulites also show the effects of microclinisation of quartz and plagioclase.

Pyroxenites

Apart from the concordant 'schleiren' of pyroxenites in the norites mentioned earlier, there are in the area, certain discordant dykes of pyroxenite. Only further work can show whether these later ones are pre- or post-metaporphic intrusions. They are not, however, visibly affected by the migmatisation.

Microfabric

The results of the petrofabric analysis of a few specimens from the area are described in this section. Two specimens each of acid charnockite and leptynite and one specimen of garnet-sillimanite-quartz granulite have been analysed. All the sections examined were cut normal to the prominent megascopic lineation (*b*-fabric axis) and parallel to the *a*-*c* fabric plane. Optic axes of quartz have been uniformly plotted on the upper hemisphere of projection. 200 to 250 quartz optic axes have been oriented and plotted for each diagram. No selection was made on the basis of shape or grain size in the choice of quartz grains for study. One of the specimens of leptynite (s. no : 2172, diagram no : 2) is from a band of the rock adjacent to the major band of garnet-sillimanite-quartz granulite (s. no : 2171, diagram no : 1), and the other (s. no : 2190, diagram no : 3) is from a lens of the rock in acid charnockite. One specimen of acid charnockite (s. no : 2110, diagram no : 5) is from a lens of the rock in a major band of leptynite; the other (s. no : 2184, diagram no : 4) from a larger mass of acid charnockite, which in its turn has small bands and lenses of both leptynite and norite.

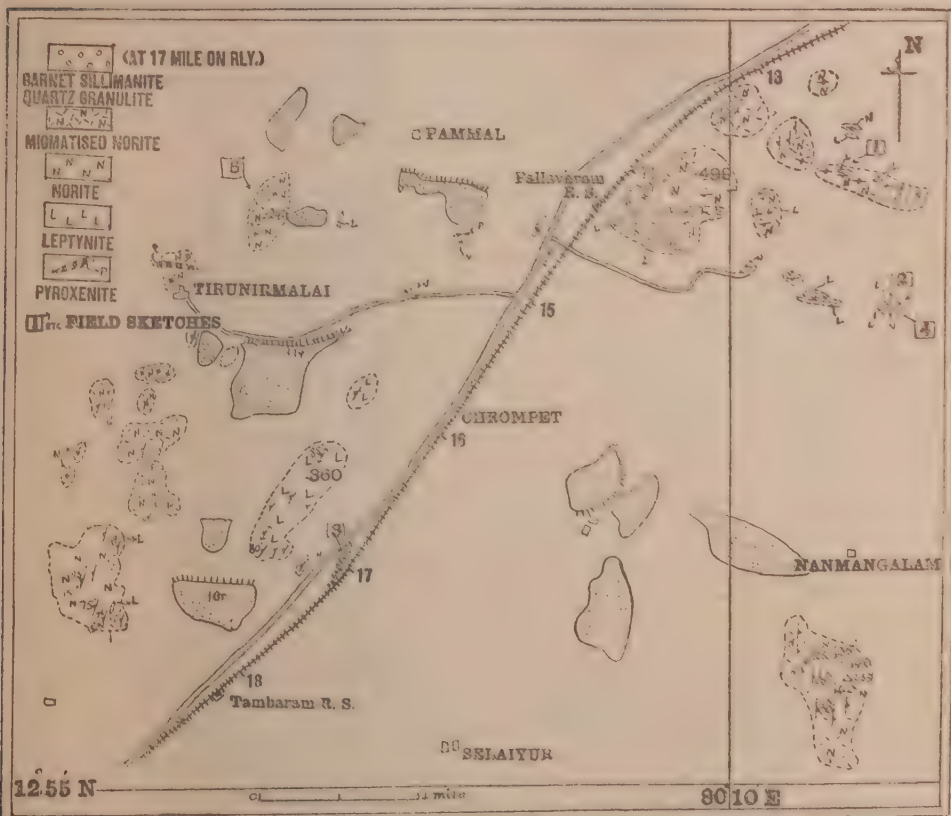
A single, fairly complete girdle of quartz optic axes (1%) is present in *all* the specimens analysed, and this forms the main feature of all but one of the diagrams made. These girdles are normal to *b*, the megascopic lineation, and are in the *a*-*c* plane of fabric axes. The lineation in the area is therefore identical with the Tummel type. The *b* (fabric) axis is also the axis of intersection of the visible and statistical *s*-planes. All the girdles are fairly long (see Table III).

TABLE III

Diagram Rock (Sp. No.)	1	2	3	4	5
	2171	2172	2190	2184	2110
Pattern of preferred orientation.	Single girdle normal to b.	Single girdle normal to b.	Single girdle normal to b.	Single girdle normal to b.	Girdle normal to b; a field of concentration with 4% maximum in middle of diagram.
a-c girdle fairly complete in all the five diagrams.					
Lengths of 1% girdles (in degrees)	328°	288°	336°	300°	270°
Contours (at 1% intervals).	1 to 10%	1 to 9%	1 to 7%	1 to 8%	1 to 5%
Number of maxima	1-3	2-1	1-7	1-1-1-1	2-2
Heights of maxima	10-7	9-6	7-6	8-6-5-4	5-4
Position of maxima	Maxima fall on or just inside the periphery of the girdle.				
S ₁ -foliation identified in the field, strike of. Lineation—b.	N35E	N35E	E10S	E10S	One maximum falls in the interior away from the periphery of the diagram.
	Very good Horizontal	Good Horizontal	Good Horizontal	Fair Horizontal	E-W Fair 15° W

N.B.—Statistical s-planes are marked by broken lines in the diagrams.

Significant concentration of optic axes in distinct maxima exist in all the rocks analysed. The maxima are all situated at or near the periphery of the diagram. The maxima are higher in the garnet-sillimanite-quartz granulites and the leptynites than in the acid charnockites.



The *a-c* girdle of quartz optic axes normal to the megascopic lineation, the length of these girdles, the approximately monoclinic symmetry of fabric, the positions of the maxima, the coincidence of the *b* fabric axis with the line of intersection of the visible and statistical *s*-plane *s*, all indicate that the rocks analysed are *B*-tectonites. The high degree of preferred orientation and the heights of the maxima are characteristic of the fabric of highly deformed rocks. The rocks examined cannot be considered, in their present state, to be igneous.

It is evident that very good correlation is available in the micro-fabric of the rocks analysed. In all but one of the diagrams, the $a-c$ girdle of quartz optic axes is the only mode of quartz orientation. Only in one specimen of acid charnockite is there any evidence of the super-imposition of another orientation pattern, though even in this rock, the girdle pattern common to the other rocks is recognizable.

The results of the fabric study in the form of petrofabric diagrams is appended; and the main features of the rocks analysed and the diagrams made are summarised in table III.

Microscopic examination of the oriented sections showed that the quartz grains occur as lenses, elongated in the direction of the lineation, b , and flattened parallel to the foliation ($a-b$ plane). It is apparent that very good correlation exists between dimensional orientation and lattice orientation. It is to be inferred that the recrystallisation of quartz in elongate, flat lenses was closely associated with the development of the lattice orientation. It follows that the multiple undulatory bands observed in quartz were formed after the development of a preferred lattice orientation, and that this final phase of deformation, essentially post-crystalline in character, did not materially contribute towards the development of the fabric. Paracrystalline deformation was, therefore, in the main, responsible for the preferred orientation in the rocks.

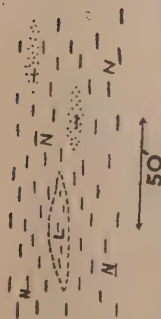
Discussion

The norites, leptynites, garnet-sillimanite-quartz granulites, and the garnet-diopside granulites (with small intercalated lenses of scapolite-calc granulite) occur as alternating, conformable bands. All these rocks are found to grade into one another at their contacts, and lenses of some of these rocks are found in norites and *vice versa* (see field sketches nos: 1 to 5).

The acid charnockite occurs as veins or bands mostly in the norite, and less often in the other rocks. In the earlier sections of this paper, it has been shown that every stage in the transition between norite, leptynite etc., on the one hand and acid charnockite on the other has been observed (see also field sketches nos. 1 to 5).

Thin sections of these transitional types to acid charnockites showed that the mineral assemblages of the original rocks are re-

SKETCH 1



NORITE



MIGMATISED NORITE



LEPTYNITE



MIGMATISED LEPTYNITE

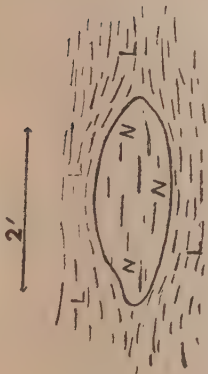


GARNET SILLIMANITE QUARTZ GRANULITE

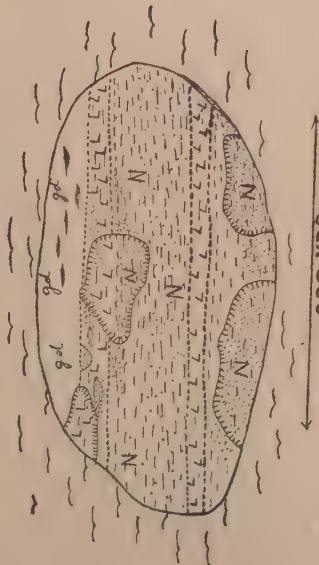
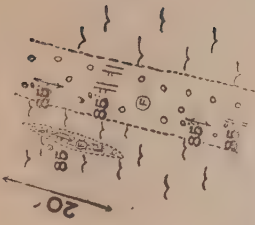


SCAPOLITE CALC GRANULITE

SKETCH 2



SKETCH 3



SKETCH 4



GARNET DIOPSIDE GRANULITE



SOIL COVER



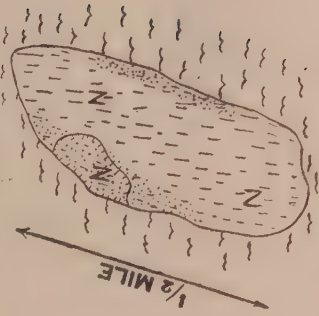
QUARRY



SHEARPLANES

© SPECIMENS FOR FABRIC STUDY

FIELD SKETCHES



SKETCH 5

placed to varying degrees by quartz/K-feldspar, until finally, by a gradual increase in the amount of replacement, the characteristic mineral assemblage of acid charnockite is produced (see Tables I and II).

The garnet-sillimanite-quartz granulites are undoubted meta-sediments in the present area. The foliation in this rock conforms to bedding and has been identified as *bedding plane schistosity*. It is interesting to note that the foliation in all the other rocks is parallel to the original stratification of this metasediment. A marked coincidence in the trend of lineation has also been noted. The single girdle of quartz optic axes normal to the megascopic lineation seen in the few fabric diagrams prepared indicates that these rocks are not magmatic and isotropic, as they exist at present, but that the fabric has been developed in the course of one major deformation.

It is difficult to speak in unequivocal terms of the ultimate origin of the norites, leptynites and the other granulites. There are features, however, which are suggestive of a sedimentary origin for them. Mention may be made of the variation of the norites to garnet-diopside granulites and scapolite-calc granulites, the general parallelism of all the structural features in these rocks to one another, the occurrence of lenses of leptynite in norite and *vice versa*, the gradual passage of one rock into another, and the general conformity in orientation pattern of all these rocks to that of the garnet-sillimanite-quartz granulites (where the fabric is related to the bedding). Further, no discordant contacts between any of the above rocks have been noted in the field.

On the basis of the present work it is possible to suggest that the 'intermediate charnockites', or the rocks composed of alternating bands of norite and acid charnockite are *migmatites*, and that they were formed by the introduction of acid charnockitic material into the original metamorphites, mainly the norites. The acid charnockites of the area would then be, at least in part, formed by a process of migmatization of the earlier rocks, viz., norites, leptynites and the other granulites. This migmatization is thought of as having taken place under the conditions of the granulite facies, and broadly synchronous with the major deformation. The enrichment in biotite of the noritic bands and stringers in acid charnockite is probably due to basification complementary to the migmatization.

ACKNOWLEDGEMENT

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Gregarious Attraction as a Factor Influencing the settlement of Barnacle Cyprids

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ABSTRACT

The Madras barnacles are as susceptible to gregarious attraction as those found in temperate waters. Gregarious attraction is directly proportional to the number of barnacles already settled and inversely proportional to the distance from them. Gregarious attraction is greatest between adults and cyprids of the same sub-species or species.

Partiality for sheltering edges and corners is possibly closely linked with a preference for the vicinity of previously settled forms, but it is very probable that gregarious attraction is biochemical in operation.

I. INTRODUCTION

The term "gregariousness" was used by Jefferys (1863-69), and Eales (1839) to denote the tendency of members of a sessile species to settle close together within a restricted habitat because of favourable conditions of food and shelter. That "gregariousness" facilitates breeding in copulatory species was also implied. Thorson (1946) demonstrated that even non-copulatory species are stimulated to spawn by crowding. Wilson (1948) suggested that the larvae of a gregarious species such as *Sabellaria alveolata* may be strongly attracted by the presence of adults or young worms already settled to settle alongside them. Cole and Knight Jones (1949) showed that the larvae of *Ostrea edulis* settle more readily on shells from which the spat had been removed, and restocking took place successfully where the left native stock was fairly great.

Burton (1949) found that the first settled larvae of *Balanus* sp. attract others to settle on the same spot.

The factors which induce gregariousness are difficult to determine. Crisp and Chipperfield (quoted by Knight Jones and Ste-

phenson '50) observed that barnacles often settle alongside surface projections sheltered from currents, and concluded that the tendency to settle in groups may be wholly due to the later arrivals obtaining some shelter from the previously settled barnacles. However, Knight-Jones (1953) showed by laboratory experiments that cyprids of *Balanus balanoides*, *Balanus crenatus*, and *Elminius modestus* settled more readily when offered surfaces which bore settled barnacles of their own species. The attraction in this case may be possibly olfactory (Knight-Jones and Stephenson '50) while the larvae of *Ostrea edulis* (Cole & Knight-Jones, 1939) were found to settle by a substance secreted into the surrounding water. Knight-Jones and Crisp '53 and Knight-Jones '53 suggest that the cypris larvae of *Balanus balanoides*, *Balanus crenatus* and *Elminius modestus* may be attracted by a quinone tanned protein present in the epicuticle of barnacles.

It will be obvious that the gregarious tendency of members of a sessile species, is important from the point of view of fouling of underwater surfaces. Hence the attraction exercised by the adult barnacles, *Balanus amphitrite variegatus*, *B. tintinnabulum tintinnabulum* and *Chthamalus stellatus stellatus* on the larvae of their own species as well as the larvae of the other barnacles was studied in detail.

To see if the cyprids of Madras barnacles settle more readily on surfaces previously fouled with barnacles, the following experiment was conducted.

Experiment 1. : Two glass plates (X and Y) measuring $5'' \times 7''$ on which a central area of $1'' \times 3''$ was demarcated on the under-surface were fixed on to a concrete slab, and several such slabs were immersed horizontally with the plate side uppermost one foot below the lowtide mark at three different sites, A, B and C* and left there undisturbed for five days. On the 6th day it was found that the plates as well as the entire concrete slab was coated with the primary film. Metamorphosed cyprids and tubiculous polychaetes were found attached to the primary film. These were easily removed with the point of a needle. Leaving those attached to the upper surface of the central area of $1'' \times 3''$ on one plate (Y)

* Site: A was at the extreme tip of the New North Quay, where only *B. a. variegatus* was found.

Site B: was at the Royapuram shore, where *B. t. tintinnabulum* was found.
Site C: was 100 yards from site B, where *Chthamalus stellatus* was found.

the rest were thus removed. The number of barnacles thus left on plate Y were counted and the concrete slab was put back in the same site in the sea, as before. After three days the slab was removed and the number of barnacles now found on the plates were counted to see if more had been induced to settle on plate Y in which the barnacles had been left intact. The extra number of barnacles settled during the three days of experimental exposure was checked against the number on the control plate X. This experiment was repeated every month at the three different sites and the data are given in Table I on page 100.

It will be obvious from the average of twelve months data that of the 1653 cyprids of *B.a. variegatus* found on the experimental plate Y at the end of 8 days, 124 were there on the central area of $1'' \times 3''$ on the 5th day and 1529 had settled on the 6th, 7th and 8th days. Since, in the control, 691 barnacles had settled on the plate during these three days ($1529 - 691 = 838$) 838 more had been attracted to the experimental plate Y because of the 124 already settled there. Therefore, it may be inferred that each barnacle previously settled is able to attract roughly 7 cyprids. However, this attraction exercised by the previously settled barnacles cannot be expected to operate in a directly proportionate manner after a certain number of days for other factors like limitation of space will limit the number of cyprids settling whether attracted by previously settled barnacles or otherwise. The number of larvae liberated into the water and the cyprids which swim into the area may also increase or decrease. Hence, the ratio of one settled adult to 7 settling cyprids may be altered after a few days, and will not be directly proportional as may be assumed theoretically. This will be obvious by a scrutiny of the large number of larvae indicated in Table I in April, May as well as in October and November. During these months production of larvae reached peak levels and the limited space offered by the plates were equally occupied in the experiment as well as in the control.

In the case of the cyprid larvae of *Balanus tintinnabulum* *tintinnabulum*, it is seen that 734 more had been attracted to the experimental plate because of the 16 settled there. Therefore the gregarious attraction for this species was found to be 1 : 46. Since the larvae of this species is not so abundant in the Madras area

TABLE I

Showing the number of cypride settled on the control plate and experimental plate.

Barnacle	Month	Experimental Plate Y			Control Plate X		Gregarious Ratio
		No. settled on central area 1" X 3" at the end of 5 days	No. settled on plate at the end of 8 days	No. settled on the plate on the 6th, 7th & 8th days	No. settled on the 6th, 7th & 8th days		
1. <i>Balanus amphitrite variegatus</i> .	Jan.	98	700	602	154	1 : 4.5	
	Feb.	48	1040	992	167	1 : 17.2	
	Mar.	74	1300	1226	140	1 : 14.7	
	April	214	2566	2352	1560	1 : 3.7	
	May	196	2230	2034	1054	1 : 5	
	June	48	1464	1416	178	1 : 25.8	
	July	96	2228	2132	124	1 : 20.9	
	Aug.	112	632	520	134	1 : 3.4	
	Sept.	86	1010	924	116	1 : 9.4	
	Oct.	206	2864	2658	2274	1 : 2.3	
	Nov.	242	2726	2484	2238	1 : 1.0	
	Dec.	62	1070	1008	148	1 : 13.9	

2. <i>B. tintinnabulum tintinnabulum</i>	Jan.	17	460	443	61	1 : 22.5
	July	14	752	738	39	1 : 49.9
	Aug.	9	1029	1019	85	1 : 103.8
	Dec.	22	899	877	73	1 : 36.5
	Jan.	19	910	891	41	1 : 44.7
	Average	16	810	794	60	1 : 46

3. <i>Chthamalus stellatus stellatus</i>	Jan.	41	1586	1545	613	1 : 22.7
	Feb.	53	3172	3119	1493	1 : 30.7
	Mar.	39	2005	1966	647	1 : 33.8
	April	16	1044	1028	228	1 : 50
	May	35	2120	2085	513	1 : 44.9
	June	66	3666	3600	1727	1 : 28.4
	July	49	3747	3698	1102	1 : 52.9
	Aug.	35	3111	3076	1004	1 : 59.2
	Sept.	16	530	514	110	1 : 25
	Oct.	58	2035	1977	938	1 : 18
	Nov.	146	4870	4724	599	1 : 28
	Dec.	96	3324	3228	1174	1 : 21

Average	54	2601	2547	846	1 : 31.5
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the spacing out tendency is not seen in this species. Similarly for *Chthamalus stellatus stellatus* the gregarious attraction was found to be 1: 31.5

This shows that gregariousness is exhibited by all the three Madras barnacles.

Experiment 2:—If the larvae of a particular barnacle were attracted by the members of the same species already settled it is probable that the intensity of attraction will be inversely proportional to the area of attraction.

Crisp and Chipperfield (as quoted by Knight Jones and Stephenson '50) have suggested that another factor namely the availability of shelters will influence the number of cyprids settling. In order to see (a) if the attraction decreases inversely with the distance and to see (b) if the cyprids prefer angles and corners to plain surfaces the following experiment was performed. A glass slide measuring 1" \times 3" and 1/10" thick was stuck with "Duco" to the centre of a glass plate 5" \times 7". Two such plates (X and Y) were fixed on to a concrete slab and several such slabs were immersed horizontally with the slide side uppermost one foot below the low tide, mark at site A, where *B. a. variegatus* abounds, and left there undisturbed as before for 5 days. On the 6th day, leaving those barnacles that had attached to the upper surface of one slide of plate (Y) the rest were removed without damaging the primary film. Even those found on the edges of the slide were carefully removed. The number of barnacles thus left on slide Y were counted and the concrete slab was put back in the sea. After three days this slab was removed and the number of barnacles that had settled on the 6th, 7th and 8th days on the control slide and its glass plate X were counted first, then those on an area (No. 1) formed by the edges of the slide and .5 inch away from it all round, then these in a second area (No. II) .5 inch still further away from area No. 1. In this way the numbers settled on 4 definite areas I, II, III and IV, .5, 1, 1.5 and 2 inches away from the slide were obtained. (To facilitate the counting these areas were demarcated by lines drawn on the concrete slab before the plate was fixed). The numbers of larvae found in the regions of both the control plate X and experimental plate Y are presented in Table II together with averages of the different numbers and the mean density of settlement per square inch.

TABLE II

Showing the number of barnacles settling in different zones round the group of previously settled adults in the experimental plate and the numbers in the different zones of the control plate where there was no previously settled barnacles.

Month	Control					Experimental				
	Slide 3 sq. "	Area I 5 sq. "	Area II 7 sq. "	Area III 9 sq. "	Area IV 11 sq. "	Slide 3 sq. "	Area I 5 sq. "	Area II 7 sq. "	Area III 9 sq. "	Area IV 11 sq. "
Jan.	37	285	122	189	231	191	420	338	310	342
Feb.	39	150	104	108	198	131	332	225	238	264
Mar.	75	190	168	186	228	244	552	444	352	396
Apr.	57	240	145	216	236	212	468	335	323	357
May	70	312	138	160	252	224	500	368	332	378
June	48	252	123	156	158	160	372	398	263	282
July	39	186	108	138	141	162	330	285	271	273
Aug.	48	204	135	198	186	186	450	315	312	321
Sept.	76	336	174	171	234	255	580	442	368	441
Oct.	29	126	87	138	138	145	348	264	288	267
Nov.	29	168	60	84	144	160	415	294	262	282
Dec.	58	288	144	132	201	186	512	330	293	314
Average	52	244.7	125.7	156.3	195.6	189.2	439.9	336.5	301	326.5
Mean density of settle- ment per sq. in.	17	48.94	17.9	17.36	17.7	63	87.98	48.1	33.4	29.68

A perusal of Table II will show (a) that the attraction increases inversely with the distance. On the slide (area of 3 square inches) fixed to the experimental plate Y, 63 cyprids had settled on each of the 3 square inches during the 3 days of the experiment whereas only 17 had settled on the slide fixed to the control plate X, suggesting that $63 - 17 = 44$ cyprids per square inch had been attracted by the previously settled adults. In zones I, II, III and IV surrounding the slide fixed to the experimental plate 39, 30, 16, 12, cyprids per square inch had settled indicating that the attraction exercised by the adults previously settled on the slide decreases as we go further away from it. Such a decrease is not noted in the control slide where 17 barnacles settled on a square inch whether on the slide or on zone IV farthest from it. (b) The second object of the experiment is also clarified by the data presented in Table II. The angles and corners of the slide fixed on the control plate X appear to have induced a larger number to settle on the area I than on the slide itself or any other area like II, III and IV. That this is due to the advantage of shelter offered in area I is obvious. In the experimental plate also the advantages of the corners and edges are responsible for the settlement of 88 cyprids settling in area I whereas only 63 settled on the slide containing the adult barnacles. Similar results were obtained for *B.t. tintinnabulum* and *C.s. stellatus* but are not presented here.

Experiment 3:—To see if the attraction exercised by the adult barnacles on cyprids has a specific character, the following experiment was performed. Four glass plates with slides stuck on them, as used in Experiment 2, were prepared with the adults of the four different species, *B.a. variegatus*, *B.t. tintinnabulum* and *Chthamalus stellatus stellatus* settled on them. All the four plates along with a control plate which had no barnacles on it but which had a thick coating of the primary film were immersed one foot below the low tide mark at site A, inside the Madras harbour, since at this site barnacles of *B. a. variegatus* abound more than the other species. The numbers that had settled on each plate were counted after 24 hours and set forth in Table III. The experiment was repeated 12 times during the whole year.

A perusal of Table III shows that of the four different species of barnacles tested, *B. t. tintinnabulum* exercised the poorest attraction though the number of cyprids settled on this plate were far more than on those which had no barnacles. Adults of *C. s.*

stellatus attracted more cyprids than those of *B. t. tintinnabulum* though they belonged to a different genus. *B. a. variegatus* attracted the maximum number of cyprids thus indicating that attraction therefore is decidedly specific. *B. a. communis* following close behind in order probably indicates the close relationship of the two sub-species.

TABLE III

Showing attachment of *B. a. variegatus* at site "A" when presented with plates bearing slides which had the 4 different barnacles.

Experiment No.	Attachment on plates which bear slides with				Control Plates.
	<i>B. a. variegatus</i>	<i>B. a. communis</i>	<i>B. t. tintinnabulum</i> .	<i>C. S. stellatus</i> .	
1	516	312	210	262	148
2	858	466	190	614	56
3	1126	892	564	614	232
4	3426	3242	2136	2846	626
5	393	186	130	164	98
6	995	376	282	314	114
7	201	92	64	86	36
8	462	210	148	182	92
9	386	200	122	144	58
10	986	424	302	386	126
11	726	444	312	394	108
12	840	354	220	310	78
Average	990.6	599.8	390	493	147.6

Experiment 4:—To assess the differences in gregarious attraction arising out of sub-specific differences, equal numbers of the larvae (50) of *B. a. variegatus* and 50 of *B. a. communis* were introduced in bowl A where there were only adults of *B. a. variegatus*. Similarly 50 larvae of each of the sub-species were introduced into Bowl B where there were only adults of *B. a. communis* and similar two lots of 50 larvae into Bowl C where there were 5 adults of each sub-species.. The influence of the attraction exerted by the adults of one sub-species on the larvae of the other sub-species was determined by noting their attachment and metamorphosis and results are presented in Table IV below.

TABLE IV

Showing numbers of larve of *B.a. variegatus* and *B.a. communis* induced to settle by adults of the two subspecies in the three different bowls.

Expt. No.	Bowl A containing adults of <i>B.a.</i> <i>variegatus</i> .		Bowl B containing adults of <i>B.a.</i> <i>communis</i> .		Bowl C containing adults of both <i>B.a.</i> <i>variegatus</i> and <i>B.a.</i> <i>communis</i> .	
	No. of larvae of <i>B.a. varie-</i> <i>gatus</i> settled.	<i>B.a. com-</i> <i>munis</i> settled.	No. of larvae of <i>B.a. com-</i> <i>munis</i> settled.	<i>B.a. varie-</i> <i>gatus</i> settled.	No. of larvae of <i>B.a. varie-</i> <i>gatus</i> settled.	<i>B.a. com-</i> <i>munis</i> settled.
1	45	35	38	30	48	46
2	44	36	44	34	37	42
3	48	29	42	32	43	48
4	50	30	48	33	42	41
5	37	34	39	28	46	42
6	45	30	45	35	49	43
Average	45	34	44	32	44	44

It will be seen from Table IV that the adults of each subspecies, *B.a. variegatus* and *B.a. communis* attract the larvae of their own subspecies to a greater extent than the larvae of the other subspecies :

Summing up, the results of the three experiments, can be generalised as follows :—

- (1) Gregarious attraction is directly proportional to the number of barnacles already settled.
- (2) It is inversely proportional to the distance from the centre of attraction.
- (3) It is influenced to a greater extent by the adults of the same subspecies, within a species.
- (4) Availability of shelters like edges and corners allow larvae to settle in large numbers which in their turn attract more larvae.

ACKNOWLEDGEMENT

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On a New Species of Shipworm of the Subgenus *Neobankia* from Madras

BY

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ABSTRACT

A new shipworm, *Bankia* (*Neobankia*) *lineata* sp. nov. is described from Madras.

INTRODUCTION

In the course of a detailed study of the Teredinidae of the Indian waters, the author was able to describe seventeen species, belonging to the genera *Bankia* and *Teredo* of which eleven were found to be new. From Cochin harbour, on the West Coast, Erlanson (1936) noted the occurrence of five species. Though these wood boring molluscs could be distributed through the agency of drifting logs and the wooden hulls of ships, it is noteworthy that *Teredo* (*Teredo*) *parksi* Bartsch, *Teredo* (*Teredo*) *furcillatus* Miller, recorded from Pearl harbour and Samoa respectively and *Teredo* (*Teredora*) *gregoryi* Dall *et al* reported from various localities in the Pacific ocean, occur in Madras waters, showing the extensive range of distribution of these forms in the Indo-Pacific area. The present paper deals with one more new ship worm *Bankia* (*Neobankia*) *lineata* of which fifteen entire specimens and several shells and pallets were collected from wooden logs washed ashore on Madras beach during January 1955.

Measurements: One specimen 5.5 cm. long has been selected as the type for description.

Shell length—5 mm, Shell height—5 mm, pallet length—24.7 mm. Stalk of pallet alone—12.6 mm. diameter of blade—1.6 mm.

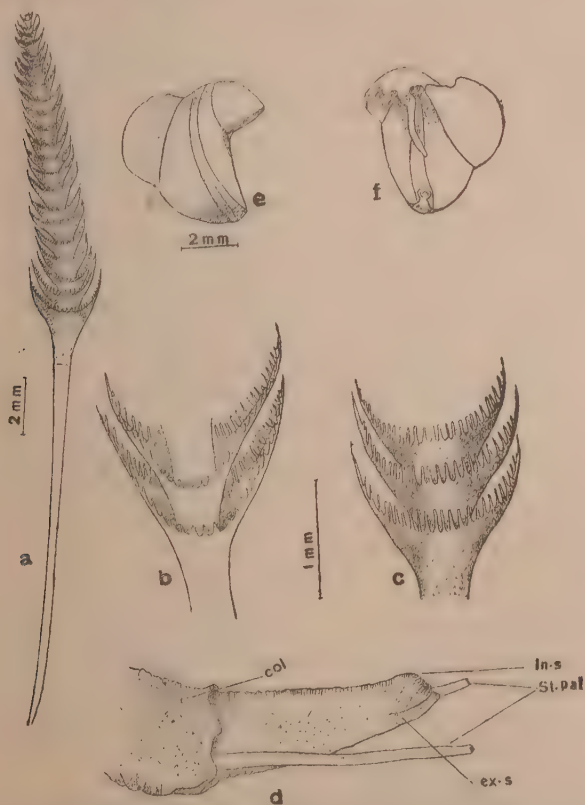
Characters: Shell globular and white. The extreme anterior margin with a moderately deep sinus edged with a strong callus the surface of which is granular. This callus is reflected over a few of the dental ridges on the outer surface of the anterior lobe of the

shell. The rest of the anterior area is sculptured by about 59 denticulated ridges which are almost as wide as the spaces that separate them, but becomes closer spaced as the shell increases in age. The free edges of these rib like ridges are provided with rows of fine denticles. The length of the anterior lobe is almost equivalent to its height at its junction with the median lobe. The anterior part of the median lobe is crossed by strong closely set dental ridges which are separated by mere impressed lines. The denticles borne by them are comparatively stronger than those borne by the ridges of the anterior lobe. The dental ridges of these two lobes meet almost at right angles. The middle portion of the median part is a smooth, slightly depressed groove, extending from the umbonal region to the extreme ventral point where the ventral knob is situated. The posterior portion of the median lobe is convex and crossed by lines of growth. This region forms a very well developed thin and almost translucent auricle (posterior lobe) which bears on its surface concentric incremental lines. Interior of the shell is smooth and white. The auricle extends over the posterior median part as a strong but narrow shelf. The umbone bears a strong knob from the inner, underside of which springs the moderately broad sickle-shaped, slightly flexed apophysis which projects into the cavity of the shell for about half the distance towards the ventral knob. The junction of the anterior with the median lobe is denoted by a tumid area.

Pallets : Feather-shaped, with a creamy white, long, fragile, cylindrical stalk which is almost as long as the blade. The blade consists of distinct well formed cone-in-cone structures (22 in the specimen figured which is slightly imperfect at the tip) the lateral borders of which are drawn out into slender processes while the intermediate space between these is strongly denticulate by about 26 prominent denticles both on the outer and on the inner margins. The inner margin of each cone of the blade forms a shallow cup where the denticles are arranged in a regular row, whereas the outer margin is deeply concave and its rim is provided with shorter and stouter denticles.

Siphons : The siphons of this species are very long and conjoint until near the extremities where it is mottled with reddish brown spots. In the preserved specimens the siphons are contracted. Both inhalant and exhalant siphons are almost of equal length but the former is decidedly broader with a trumpet shaped tip. A well-developed collar is present at the base of the siphons.

The foot of this form is heart-shaped, labial palps are reduced, the branchial region comparatively short and the caecum is considerably elongated. Specimens when removed from their burrows and kept in a bowl of sea water ejected a constant stream of gonadial elements. The burrow is lined by a calcareous tube which is nonadherent to the walls of the burrow. The presence of these shipworms in a piece of timber can easily be detected by the long almost white feather shaped pallets which protrude through the small openings in the wood.



- a. Pallet inner face.
- b. Outer face of two cups of the pallet showing nature of denticulations.
- c. Inner face of three cups of the pallet.
- d. Posterior end of the animal showing the collar (col), inhalant siphon (in. s), exhalant siphon (ex. s), and the stalk of the pallet. (st. pal.).
- e-f. Outer and inner faces respectively of the shell.

Remarks : Of the three genera *Bankia*, *Teredo* and *Bactronophorus* which constitute the family *Teredinidae*, the present form clearly belongs to the genus *Bankia*, because the pallets consist of a series of cone-in-cone structures. This genus *Bankia* established by Gray in 1840, includes four subgenera namely, *Bankia* Gray 1840, *Neobankia* Bartsch 1921, *Bankiella* Bartsch 1921, and *Nausitora* Wright 1865. The present form comes under the subgenus *Neobankia* since the cone-in-cone elements are covered by a thin membrane, denticulate at the free margin. This subgenus, established in the year 1921, on the basis of the specimen *Bankia* (*Neobankia*) *zeteki* by Bartsch now includes about sixteen species. The forms before me resemble (1) *Bankia* (*Neobankia*) *hawaiiensis* Edmondson, (2) *Bankia debenhami* Iredale et al., and (3) *Bankia occasiuncula* Iredale et al., in the general features of the shell, but differs from the first in the possession of a pallet with about 22 well-defined and distinct cone-in-cone structures when the overall pallet length is 24.7 mm. It differs from *Bankia debenhami* not only in the number and nature of the denticles on the free border of the cups but also in the number of the cutting ridges on the anterior lobe of the shell. Further the relative proportions of the shell and pallet are also very different in the two forms. *Bankia occasiuncula* is described as having a pallet covered with a film and the cones of the blade somewhat angularly cupped and a little distant, with continuous edges and indistinct, coarser, denticulations on the inner surface, obviously differing from the form in question. Hence the present form is described as a new species *Bankia* (*Neobankia*) *lineata*, and can be defined as follows :—

Bankia with a distinctly linear pallet, the blade of which is equivalent to the length of the stalk, the former composed of 22 cone-in-cone elements when the overall length of the pallet is about 25 mm. the free border of the cups bearing 26 well-developed denticles and with a shell whose length is equal to its height having a well-marked, thin, translucent auricle.

Types : The type will be deposited in the Zoological Survey of India, Calcutta, and the paratypes will be in the Zoology Laboratory, Madras.

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Fat Contents of the Red Mullet, *Upeneus Indicus* (Shaw)

BY

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ABSTRACT

The fluctuations in the fat content of the whole fish are not only related to the quantity of food consumed but also to the composition and fat-quality of the diet.

The fat contents of the different storage depots are interrelated both in storage and depletion.

When the gonads mature, the fat required by them appears to be withdrawn from the fat depots.

I. INTRODUCTION

We owe our knowledge of the fat contents of fishes, to several authors who had studied the fishes of temperate waters. While Marshall, Nicholls and Orr (1939) estimated the fat content of the whole herring, Lovern (1938) assessed the fat value of the gutted fish. But Greene (1914, 1919), Johnstone (1915, 1918, 1919, 1920), Lovern and Wood (1937), Dixon (1937), Wimpenny (1938), Wilson (1939) and Hickling (1945) studied muscle fat alone and Greene (1921) concentrated on the fat contained in the gonads only. However, Milroy (1906, 1907, 1908) estimated the fat contents of both the muscle and the gonads. Bull (1928) assessed the fat values of the muscle and the liver and Wimpenny (1938) those of the liver and the gonads. But Bruce (1924) estimated the fat values of the muscle, liver and gonads. Channon and el Saby (1932) determined the fat contents of the muscle, liver, intestine and gonads. Wilson's (1939) suggestion that skeletal tissue, especially the vertebral column (the spongy parts of the vertebrae and their hollows, as also the grooves and canals of the neural and haemal spines) and the skull may also be a fat depot has not been investigated by any. On the other hand, in discussing the factors responsible for fat fluctuations in fishes, these authors emphasised

the importance of one or the other tissue even to the exclusion of the others. However, in an organism like the fish, the different tissues may be interrelated both in the increase and decrease of their fat content, so that the fluctuations in all the tissues which can store fat must be followed in order to obtain a comprehensive picture of the fat economy of any fish.

In this paper *Upeneus indicus*, which occurs in the inshore waters of Madras from September to March, has been dealt with in relation to feeding, fat storage and maturity.

II. SAMPLING METHODS

A random sample of the day's landing was brought to the laboratory. Of this about ten fish of this species were so selected as to include different size-age groups netted during the week. Since the scales of tropical fish lack 'winter rings', determination of age is not possible and one has to rely on length and maturity stages.

Each fish was wiped free from the adherent matter like slime and loose scales and the length of the body was measured from the tip of the snout to the longest caudal fin ray. The sex and the stage of maturity of the gonads were determined. About ten fish of the same maturity stage and sex were taken for further analysis. As a rule, however, maturity was regarded as the most important variable, and fish samples were so selected for fat analysis, that all the stages, from the immature, to the spawning and spent were included. The alimentary tract of each fish was carefully removed and the stomach separated from the intestine. The stomach contents were emptied into a dish by cutting it open, while the rest of the gut was evacuated by gentle pressure, as too much handling may occasion some loss of fat (Channon and el Saby, 1932). The stomachs and the intestines were weighed together with the ten fish and the average weight of a single fish was obtained. After this, the livers of the ten fish were put together and weighed as one lot, and the average weight of a single liver was obtained. The intestines and the gonads were similarly treated. A thin longitudinal slice of muscle was cut along a line running from the pectoral region to the caudal (*vide* Bruce, 1924; Channon and el Saby, 1932), after removing the scales along the tract. Slices of muscle and skin thus obtained from the sample of the day were set apart for fat extraction. The remaining muscles were removed

from the vertebral column and the head and the skeletal system (with the nervous system) together with the scales and fins of all the ten fish was weighed as one lot, and an average was obtained. To the average weight of this residual tissue was added, the average weights of the liver, intestine, and gonads and when subtracted from the average weight of a single fish, the average weight of the muscle was obtained.

Muscle slices obtained from the fish were chopped (Bruce, 1924) and thoroughly ground in a mortar and about 10 grams of the pulp was accurately weighed and dried at 105° C. (Lovern and Wood, 1937) to constant weight in four hours. The dried tissue was weighed again and was ground in a clean and dry mortar. The powdered material was transferred to a filter paper thimble which was placed in the extractor of a Soxhlet extraction apparatus. The mortar and pestle used for grinding the dried material, as well as the funnel were washed twice with small quantities of ether into the thimble. The powdered tissue was subjected to continuous extraction with anhydrous ether for eight hours to constant weight. The weighed flask with its contents was freed from the remaining ether by keeping it in an oven at 40° C., cooled and weighed. The increase in weight gave the amount of fat or 'ether-soluble matter' present in the tissue taken for analysis. Similarly the liver, intestine, gonads and the residual tissue were extracted for fat separately.

In order to correlate the fat contents of fishes to the quantity as well as the fat-yielding quality of their food, the crustacean and teleostean items of the stomach contents of a large number of fish were separately weighed after identification and their fat contents assessed. To find the rate of feeding, the total weight of food obtained was divided by the number of fish analysed in the day's sample.

In determining the maturity stages of fishes the standards defined by the International Council for the Exploration of the Sea were used (Lovern and Wood, 1937).

Since fat percentages do not give an idea of the absolute changes involved in the fat contents of the fish body, the fat values of the whole fish and its tissues are given as grams of fat. To study the amount of fat income to the fish and for purposes of comparison, the food-fat is also given as grams per fish.

III. Nearly 1,070 individuals of this market fish were studied during the four years 1950-54 at a rate of about 40 fish each month, from September to March. The fish measured 13.0 to 17.5 c.m.

During the seven months of its sojourn in Madras waters, this red mullet feeds mainly on crustacea like *Acetes erythreus*, decapod larvae, small crabs like *Charybdis* sp. but also on juveniles of different species of fish (as can be inferred from the presence of fish scales, vertebrae, cranial pieces, eye balls etc.) of a very small

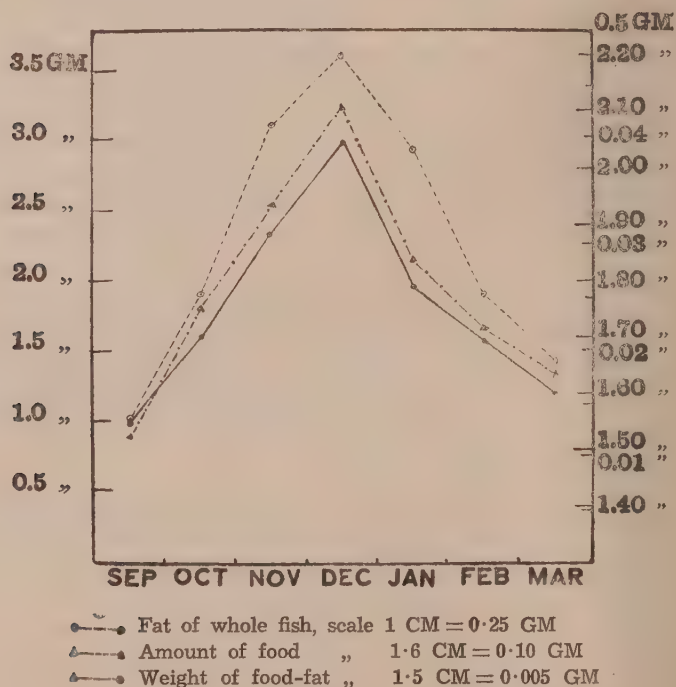


FIG. 1. To show the relationship between the fat content of the whole fish of *Upeneus indicus* and the amount of food and food-fat consumed in the various months.

quantity in proportion to the crustacea it consumes. There is an increase in the amount of food consumed per average fish from September to December (Figure 1) but the fall during January, February and March is obviously because this fish is not able to alter its menu to larger swift swimming crustacea like *Penaeus* sp. which appear during this period in larger numbers.

Nevertheless even when it feeds less, this fish adheres to its favourite diet consisting mainly of *Acetes* and *Charybdis* and decapod larvae and negligibly small proportion of teleostei. This fish does not also appear to make up for the scarcity of its favourite crustacea, by an increase of the teleostean item of diet during that period, probably because of its confirmed gustatory preferences. However, the teleostei consumed from September to March average 0.02 gram per month only.

When the quantity of food consumed during the different months, their composition and the fat income from food are studied in relation to the fat fluctuations in the whole fish, (Figure 1) we

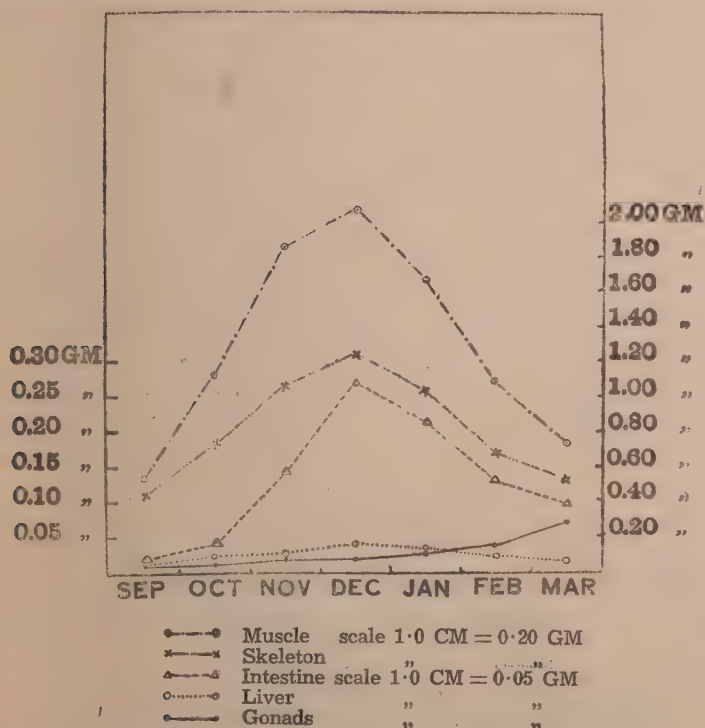


FIG. 2. The amount of fat in the different tissues of the red mullet in the various months.

find that the rise and fall in the amount of fat of the whole body of an average fish are not so directly related to the weight of the food (chiefly crustacea) consumed alone. This is because the fat

yielding capacity of the food items also increases from September to December i.e. from 0.9% to 1.9% when the highest fat percentage in the crustacean item is reached, whereas in January February, and March it falls to 1.4%, 1.2% and 1.0% respectively.

The amounts of fat in the muscle, skeletal tissue, intestine and the liver increase in the order mentioned from September to December and decline subsequently in January, February and March, (Figure 2). Considering the large amounts of the fat contained

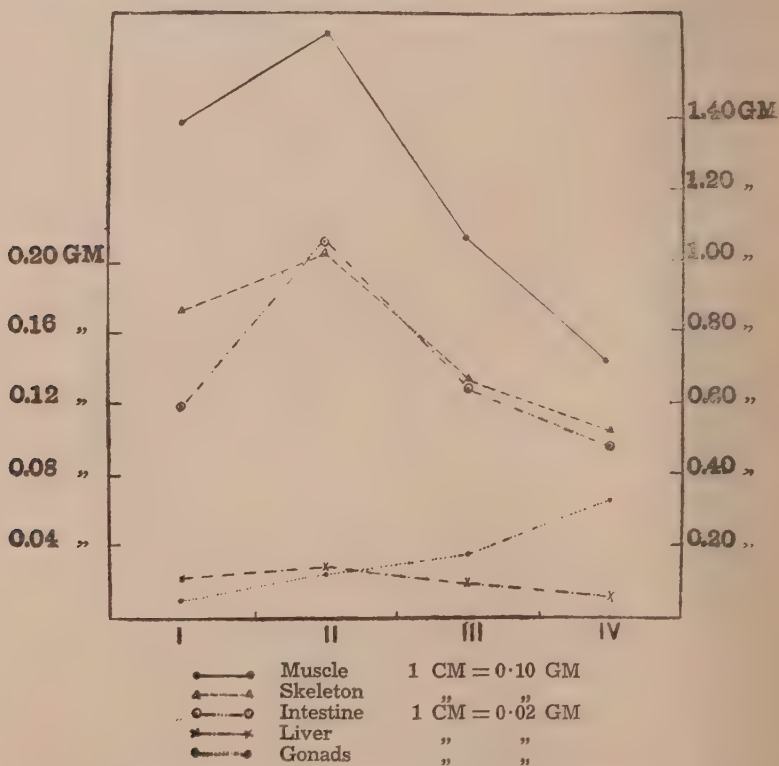


FIG. 3. The amount of fat in the different tissues of *Upeneus indicus* in various maturity stages.

in the muscle and the skeletal or residual tissue, which fluctuates in such a way as to be responsible for the rise and fall of the fat of the whole body (Figure 1), it is legitimate to conclude that the increase and decrease of fat income from food are closely indi-

cated in these depots, which probably in this fish serve as the depot for immediate storage. It is also observed that the fat content of the liver is very low during these seven months ranging between .01 gm. to .03 gm. The quantity of fat in the intestine reaches the maximum in December. Since the fall in the fat content of this depot in January, February and March is not closely related to the reduced amount of fat income from food, it is probably related to the maturation of the gonads taking place during this period.

During the seven months viz., September to March when the gonads were of a suitable size for fat extraction the fish progressed from maturity stage I in January to II and III in February and IV in March. Figure 3 shows the fat values of the depots as well as of the gonads in the different maturing stages. A careful study of the figure would show that the gonads gain fat steadily from stage I to a maximum amount in stage IV. From the figure it will also be obvious that the gain in stage II is accompanied by gain in fat depots as well. This is because of the relative increase in the fat income from food occasioning a fat gain in all the organs of the body in January. But in stage III and IV the gonads continue to gain in the face of a decreasing fat income. This must be accounted for by fat transference from fat depot like the intestine. It would be legitimate to conclude that the marked fall in the muscle and the residual tissue fat in III and IV stages is probably due to the fish falling back upon the fat stored in these organs, at a time when the fish receives food not only less in quantity but also poor in fat yielding quality.

ACKNOWLEDGEMENT

I thank Professor C. P. Gnanamuthu, Director, Zoological Research Laboratory for suggesting this problem and guiding me throughout the course of the present work.

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A Note on Semi Uniform Spaces

BY

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ABSTRACT

A family F of 'surroundings of the diagonal' of the Cartesian product set R^2 gives to R a 'semi-uniform structure', if each A in F contains the relational product $B.B$ of some B in F . The topology or neighbourhood structure, of such a space R is shown here to be merely that of a v -space (of M. Fréchet). The existence of a total family of upper semi-continuous functionals gives another characterisation of such a space.

By a "neighbourhood structure" (or NS) for a set R , we shall mean an association of a family of subsets containing x (the neighbourhoods of x), for each point x in R . Continuity of a function of R in S at a point or over a subset of R can then be defined as usual, relative to given NS for R and S . Such a NS can be derived for R in terms of a "generalised uniformity" (or GU) for R , which is a family of subsets of the cartesian product set R^2 each of the subsets containing the diagonal (and called the surroundings of the diagonal): if F is this GU, we set Ax , for A in F , to be the set of y in R for which (x, y) is in A , and take the family of Ax , A varying over F , as the neighbourhoods family at x .

By assuming three axioms for these A from F , A. Weil (1938) defined the space of uniform structure and showed that it is a space in which every point can be separated from any closed set not containing it by a continuous functional, that is, it is a completely regular space, and conversely any completely regular space has a NS determined by such a uniform structure. The corresponding question when continuous functionals are replaced by upper semi-continuous functionals has a surprisingly simple answer. We show here that the following conditions on a NS space (or set with NS structure) are equivalent:

(i) for each x in R and to each neighbourhood u of x , another neighbourhood v of x can be found such that u contains a neighbourhood of each point in v (we shall call such a NS space a v -space);

(ii) for each x in R and to each neighbourhood u of x a functional $f(x)$ can be found which is zero at x and one outside u , and is upper semi-continuous (i.e., continuous when the real continuum is topologised by assigning to its points x right half open intervals $[y \mid (y < a)]$ containing x — so that $x < a$ — as neighbourhoods);

(iii) the NS is derivable from a GU with the additional property that to each A in the Family, F , of surroundings of the diagonal, there is a B in F such that the relational product $B.B$ is contained in A (R with such a GU may be called a semi uniform space).

(i) implies (ii), as the open sets defined in terms of the neighbourhoods now give a new equivalent NS (when the open sets containing a given x are taken as the neighbourhoods of x). If the characteristic function of a open set g contained in a given neighbourhood u of x , and containing x , is $f(x)$, so that $f(y)$ is zero for y in g and one for y outside g , then f itself is upper semicontinuous. (ii) implies (iii); for assuming (ii), associate an upper semi continuous functional of the sort described for each pair (x, ux) consisting of a point x of R and a neighbourhood ux of x ; and for any positive real number e and such a functional f define $E(f, e)$ as the set of pairs (x, y) from R^2 for which $f(y) < f(x) + e$; the family of all such subsets of R^2 determines a semi uniform structure for R , for which the derived NS is equivalent to the originally given NS (we usually consider equivalent NS as the same). Finally if (iii) is assumed, (i) is easy to prove for the derived NS.

I. Konishi, who has introduced the GU (in effectively the same manner as here), has considered notions of completeness and a process of completion of spaces with a GU. This gives in effect a method of associating to v -spaces certain GU structures and completions of the GU spaces so obtained. The nature of the completed spaces thus obtained is to be investigated. The above result also shows that the axiom of symmetry for a GU is important in order to arrive at completely regular spaces as the derived NS spaces. The question of symmetrising a GU or a NS space will be considered in a subsequent paper.

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Heterocyclic Compounds Part V

Synthetic compounds structurally related to the Alkaloids
"Evodiamine and Rutaecarpine" (3 : 4-Quinazoloneyl quinazolines)

BY

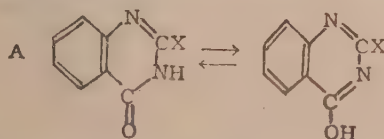
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(Received for publication, 22 February, 1955)

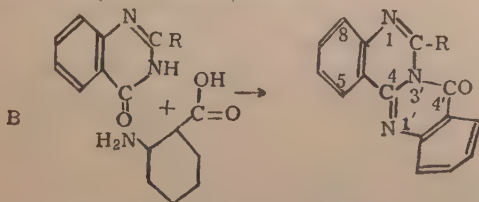
ABSTRACT

The synthesis of a few quinazoloneyl-quinazolines is reported.

Asahina, Manske and Robinson (1927) in their synthesis of rutaecarpine effected a condensation between a body containing the grouping -CO-NH- and anthranilic acid by means of phosphorus trichloride and encountered no difficulty in synthesising a quinazolone which fact seemed possible to Aggarwal and Ray (1929) to fuse a further quinazoline ring to 4-oxyquinazoline in the 3 : 4-position if it really assumes this structure in its tautomerism.



To test this point Aggarwal and Ray (1929) condensed 2-phenyl-oxy-quinazoline with anthranilic acid and were able to isolate 3 : 4-quinazoloneyl quinazoline, the colour reactions of which are very similar to that of alkaloid rutaecarpine.



A search of literature showed that the paper of Aggarwal and Ray did not attract much attention. It seemed of interest to the

present worker to prepare such compounds which appear capable of further extension. Aggarwal and Ray have prepared a few 4-oxy-quinazolines by condensing acylamines with ethyl carbamate using a large excess of phosphoric oxide as the condensing agent. Xylene was used as a diluent in the reaction.

A few 4-oxy-quinazolines which were not condensed with anthranilic acids before were synthesised. The compounds synthesised were: —

2 : 8-Dimethyl-3 : 4-quinazoloneyl quinazoline,

— 2-Methyl-8-methoxyl-3 : 4-quinazoloneyl quinazoline,

and 6 : 7 (5 : 6)-Benzo-2-benzyl-3 : 4-quinazoloneyl quinazoline.

The above work was carried out under the supervision of Dr. K. N. Menon and the author wishes to acknowledge her thanks for the help and guidance received.

EXPERIMENTAL

2 : 8-Dimethyl-3 : 4-quinazoloneyl-quinazoline:—

2 g. (1 mole) of 2 : 8-dimethyl-4-oxyquinazoline and 4.2 g. (3 moles) of anthranilic acid are powdered well, mixed thoroughly and transferred to a 150 ml. round bottomed flask fitted with a water condenser provided with a calcium chloride guard tube. 25 ml. of phosphorus trichloride were added to the mixture and the flask heated over a water bath for five hours. After the end of the reaction the phosphorus trichloride was distilled off. The solid compound was then decomposed with ice water. The substance which separated was collected and crystallised from ethanol. It formed yellow needles m.p. 250°.

calculated Nitrogen 15.21% Found 15.64%

2-Methyl-8-methoxy-3 : 4-quinazoloneyl quinazoline:—

1.5 g. of 2-methyl-8-methoxy-4-oxy quinazoline and 3 g. (2.5 moles) of anthranilic acid and 25 ml of phosphorus trichloride were refluxed as above for 5 hours. The substance after working up was crystallised from ethanol. It formed pale yellow needles m.p. 260°.

The substance is readily soluble in both 5% alkali and 1 : 1 hydrochloric acid in the cold.

calculated Nitrogen 14.32% Found 14.23%

2-Benzyl-6 : 7 or 5 : 6-benzyl-3 : 4-quinazoloneyl quinazoline:—

2 g. (1 mole) of 2-benzyl-6 : 7 or 5 : 6-benzo-4-oxy quinazoline and 2 g. (2 moles) of anthranilic acid and 20 ml. of phosphorus trichloride were refluxed for five hours and the substance worked up as above. It was collected and boiled with 1 : 1 hydrochloric acid, filtered, washed with water, pressed and dried well. The dried substance was boiled with absolute alcohol, filtered and was allowed to crystallise from absolute alcohol. It formed fine needles melting at 276°.

calculated Nitrogen 10.85% Found 11.3%

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